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FIELD MARSHAL LORD MONTGOMERY INSPECTING LAND MINE DETECTORS AT THE WITTON WORKS.

Field Marshal Lord Montgomery (then General Sir Bernard Montgomery, K.C.B., D.S.O.) made a special visit, shortly before "D" Day, to inspect land mine detectors being manufactured at the Witton Works. The illustration shows him witnessing a test of one of the equipments.

Details of these detectors are given on pages 32 and 33.

Electrical Progress and Development

By H. W. RICHARDSON, B.Sc., M.I.E.E.,
Editor of the G.E.C. Journal.

INTRODUCTION.

IF the full story of the wartime technical achievements of the G.E.C. could be published, it would fill many volumes; even a list of the individual sections of Science and Engineering in which the staff of the Company was engaged would cover several pages. In the review of progress in our last volume* an outline was given of some of the less spectacular war activities, and reference could be made only by name to some of the subjects of outstanding importance whose development contributed in so striking a fashion to victory. But now much of the veil of secrecy has been lifted, and it is the main purpose of this article—subject to limits of space—to consider some of the technical background which led to the production of apparatus and equipment of the widest variety; in many cases the magnitude of the production was enormous.

The variety of the production is indicated briefly by mentioning that important contributions were made to Mulberry (the prefabricated harbour established off the Normandy coast on D-day), Pluto (the petrol pipe line under the English Channel), and Fido (the fog dispersion apparatus for aerodromes), and that the main classes of plant and appliances manufactured included aircraft carrier lifts, turbo plant and electrical machinery of every kind, switch and control gear, transformers, rectifiers, traction equipment, Radar and communications sets, lamps and fittings, valves, cables and wires; heating, cooking and ventilating apparatus, instruments and meters, carbons, batteries, X-ray and electro-medical equipment. The remarkable extent of the variety of production, however, could not be judged adequately from this list. It will become more apparent in later sections of this article.

Some of the most outstanding production records are the following:—

1,100,000,000 core yards of cable and wire.
1,000,000,000 carbons.
300,000,000 moulded insulation parts.
100,000,000 battery units.
85,000,000 electric lamps of 300 types for Fighting Services alone.

Other production records though not of the same gigantic order as the foregoing are no less impressive, having regard to the classes of apparatus to which they apply. A few such examples are:—

2,000,000 yards of V.H.F. cable.
750,000 small electric machines and motor driven apparatus.
500,000 instruments of 200 different types.
100,000 telephone and radio sets.

Though this article is largely concerned with the technical side of the G.E.C. war effort, it should be recorded that in the latter months of 1945 much attention was directed to the provision of new equipment for the post-war period, and in particular to that best suited for export. The Company has been able to maintain its extensive export organisation intact during the war—except in territories such as China, Malaya and Burma, which were overrun by the enemy—in spite of the shortage of staff due to the needs of the Services. The end of the war with Germany and Japan thus found the G.E.C. ready to embark on the vital export drive, but the shortage of labour has prevented it from taking full advantage of the opportunity up to the present. The position is, however, gradually improving and better supplies will be available as the year goes on. Active steps have been taken to re-open the branches in China, Malaya and Burma.

RADAR AND COMMUNICATIONS.

During the war years rapid advances were made in radio engineering, and the G.E.C. made many contributions to this field in research, development and production. Radar has accelerated the trend towards higher frequencies, frequencies of the order of 10,000 Mc/s. (3 cm. wavelength) now being common for production apparatus, and much experience has been gained in the technique of using circuits for wide frequency bands.

* "Electrical Progress and Development," *G.E.C. Journal*, Vol. XIII., No. 3, February, 1945.

Details of these detectors are given on pages 32 and 33.

In addition to complete Radar and communication equipments, there have been many advances in valves, cathode ray tubes, and other components. Many new types of thermionic valve have been developed, and the resonant cavity magnetron and the "cartridge" crystal have formed the basis of centimetric Radar.

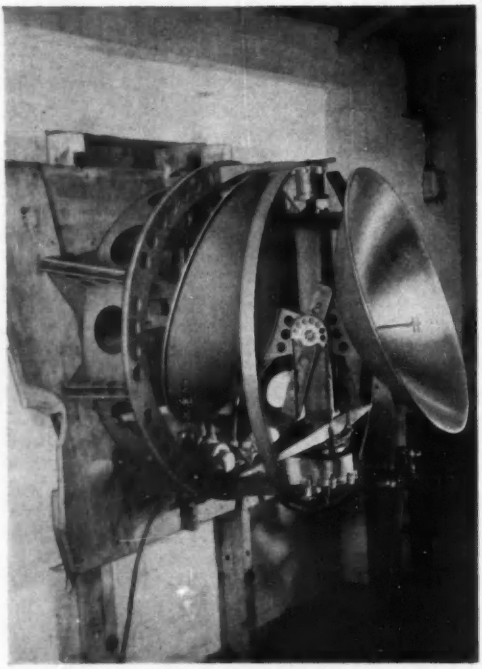


Fig. 1.—Scanner for use at centimetre wavelength.

The whole of the Company's television development resources during the war was devoted to Radar problems. The improvements in valve technique and circuit design that have occurred during this period are now being utilised to the full in work that is going on to extend and improve television technique; among the developments in this field is the design of a new range of television receivers in readiness for the re-opening of the B.B.C. Television Service.

RADAR.

Aircraft Interception. (A.I.)

Much of the G.E.C. effort on Radar during the war has been directed towards the design and development of complete systems operating at centimetric wavelengths. These short wavelengths were necessitated by the operational need for higher accuracy of location of enemy targets (particularly at lower altitudes) than was possible with the longer wavelength systems, greater freedom from enemy interference, and the demand for apparatus small and robust enough for incorporation in aircraft.

The problem involved two main groups of work—the basic research work, in parallel with that on valve design, to provide efficient transmitter and receiver circuits in the then almost unexplored waveband from 30 to 10 cm. and the development of complementary modulation equipment for providing high power driving pulses (of the order of 150 kW for 1 microsecond at a recurrence frequency of a few kilocycles). Wideband amplifier receiver circuits, timing circuits and methods of presentation to the observer also had to be developed.

Out of this work, which was carried out in co-operation with Telecommunications Research Establishment (M.A.P.), came the first Aircraft Interception system in the 10 cm. wavelength. This was first flown experimentally in February, 1941, and Radio Works started small scale production shortly afterwards. It later became known as Radar A.I. Mark VII, and was fitted in Beaufighter night-fighter aircraft. The radiated power was of the order of 5 kW peak and the radiating system produced a scanning beam. All the information required by the observer to locate the enemy aircraft and to close in to within attacking range

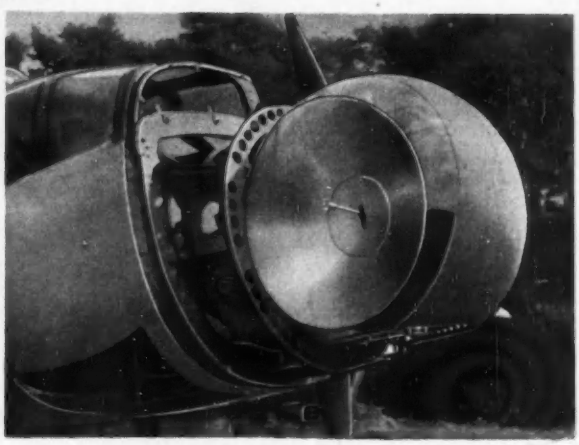


Fig. 2.—Scanner mounted in the nose of a Beaufighter.

was presented on one cathode ray tube. The accuracy of the system and its ability by virtue of its narrow radiated beam to operate at low altitudes probably made it a major factor in the eventual reduction of night raids on this country. At a critical time it also formed the mainstay of the night defence of Malta.

A further system, A.I. Mark VIII, with considerably increased operational facilities, was asked for, for larger scale production. In principle the same as A.I. Mark VII, the new system had its radio frequency power increased to 50 kW to give increased range of operation, and provided additional facilities, in conjunction with ground beacons, for homing to base station from distances of 100 miles, for blind approach landing, and for the identification of friendly or hostile aircraft. In addition an electronic range marker gave increased accuracy of range indication. The equipment was designed for use at the maximum night-fighter altitudes. This equipment (A.I. Mark VIIIa), which was first produced by Radio Works, was initially fitted in Beaufighter and subsequently in Mosquito night-fighters. During trials these systems were also used to provide basic information for the use of centimetric equipment against surfaced or partially surfaced submarines.

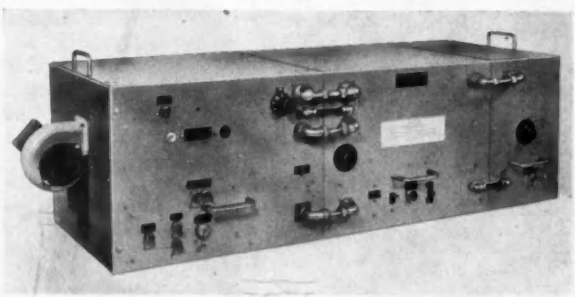


Fig. 3.—Centimetre wavelength OBOE ground station.

Considerable effort was devoted to the development of scanners for use at centimetre wavelengths, particularly of the type designed to give a television type picture of the space ahead of the aircraft. The outcome was the scanner shown in figs. 1 and 2, which was designed for use in the nose of a Beaufighter. It has two mirrors back to back with contactless switching of the 10 cm. energy between them so that only the mirror in the forward hemisphere is operative. This scanner formed the basis of the initial experimental tests of the H_2S blind bombing system.

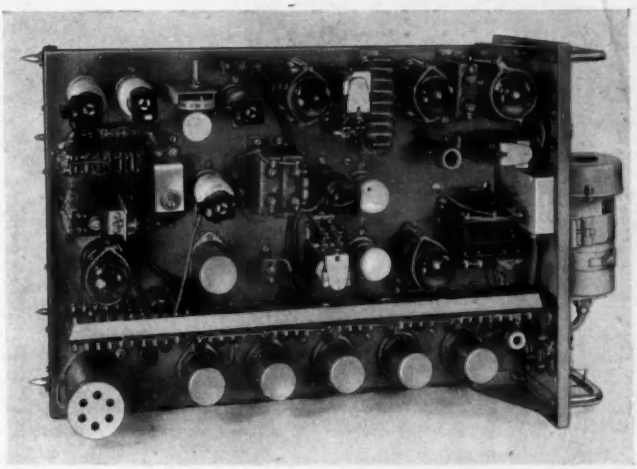


Fig. 4.—Centimetre wavelength OBOE airborne receiver.

Blind Bombing—Oboe.

As the main operational effort turned to the offensive, development was started of a centimetre version of the existing high accuracy blind bombing (Oboe) system (figs. 3 and 4). Again the objectives were an increase in accuracy, freedom from enemy interference, and operation at the maximum altitude attainable by Mosquito Pathfinder aircraft. Design work was carried out on both the complete aircraft equipment and the radio part of the associated ground equipment, and after experimental trials this system was used very successfully in the later stages of the bombing of the Ruhr and other targets.

Centimetric Aerials and Circuits.

All the Radar systems developed have called for the design of aerial systems, to attain the required beam shapes, to match them to their associated transmitting valve and feeder systems, and to make them suitable for use with high peak transmitter powers at high altitudes. Considerable experience has been gained with the use of coaxial and waveguide trans-

mission lines, and with terminations and couplings for them; many such components have been moulded in the low loss plastic dielectric, polythene. Apparatus has been set up for measuring impedance and aerial polar diagrams at frequencies up to 10,000 Mc/s. and with its aid dipoles for A.I. Scanners, the centimetric Oboe aircraft aerials and ground station aerials, and components for H_2S and similar scanners have been designed.

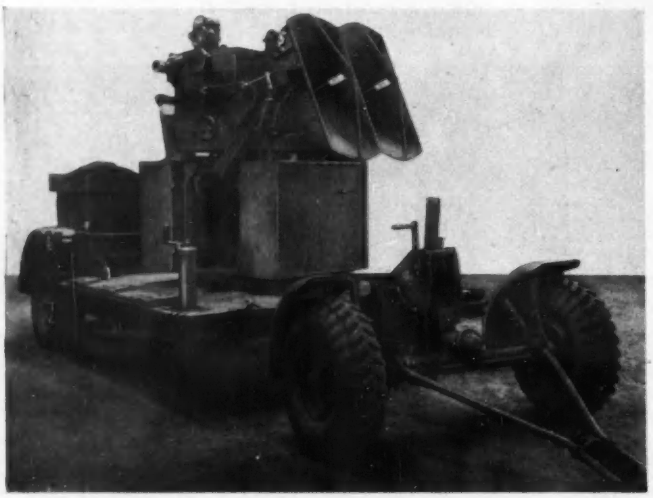


Fig. 5.—Mobile ground Radar equipment for automatic control of anti-aircraft guns.

Gun Ranging.

Radar work on gun ranging systems which was started for the Ministry of Supply in the middle of 1941 led to the development of a gun-ranging equipment (known as R_1D.F. A.A. No. 6 Mk. I), operating in the 25 cm. wavelength region, for operation against low-flying aircraft. This equipment fed accurate range information to a predictor, the combined apparatus being mounted on a trailer so as to be transportable with the associated guns (see fig. 5). An enclosed air circulating heat exchange system was provided to eliminate the effect of external temperature and climatic conditions.

The receiver tuned automatically to the transmitter frequency, which was controllable over a small range to enable the operator to avoid enemy jamming. It was eventually used in conjunction with Bofors guns for the defence of this country against flying bomb attacks.

A further gun ranging project, C.R.F., was developed for the Admiralty for use with Oerlikon guns protecting merchant shipping against low-flying aircraft (fig. 6). This equipment operated in the 10 cm. wavelength region and was mounted on the gun platform.

A number of radar equipments was also made for the Admiralty for long-range gun-laying in darkness or fog. These proved their worth in the Battle of Cape Matapan, and in the sinking of the German battleship *Scharnhorst*.

Atmospheric Absorption.

When the practicability of centimetric radar was under discussion in the early days of the war, it was not unreasonable to expect that at sufficiently short wavelengths the absorption and scattering effects due to rain, hail, fogs and clouds—which are negligible at ordinary wavelengths—might result in the signal strength becoming abnormally attenuated, or that the scattering of the radiation in a backward direction might confuse or even obscure the echoes from objects whose presence it was desired to detect.

The question could not then be settled experimentally, and in 1940 a detailed theoretical treatment, covering fog, mist, drizzle, tropical rainfall, hail and sand storms was undertaken. The results were incorporated in a comprehensive report, issued in 1941, which enabled the degree of trouble to be expected from these various causes to be assessed in respect to any given operational conditions.

Later, when detailed measurements of the attenuation effects were made, it was found that the observed values agreed very closely with the early predictions provided at the critical time.

Radio Countermeasures.

An important, if unspectacular, side of radio in war-time was the detection and jamming of enemy radio signals, and a number of different types of equipment, including airborne sets, were developed for these purposes.

Transient Testing.

The demands of Radar, television and all

spheres of communication work for circuits of greater and greater bandwidth and of more closely specified performance have called for a means of assessing accurately the operational characteristics of such circuits without resorting to the indirect and laborious method of measurement of amplitude and phase variation with frequency. This need has been met by a transient test set, whereby the behaviour of any circuit or network is given visually in terms of its time response to a very short impulse. At present, impulses of the order of 0.01 microsecond are used, and the time response characteristic is displayed on a cathode ray tube with a writing speed of about 4 inches per microsecond. With this equipment (fig. 7) it is possible to observe continuously the effects of change of circuit parameters on the transmission characteristic.

Fig. 7.—Transient test set.

Pulse Transformers.

The development of Radar and radio equipment for aircraft has resulted in corresponding advances in the design of power supply equipment, especially small transformers for H.T. and filament supplies. Particular interest attaches to those for delivering high voltage rectangular pulses of power ranging from 100 kW to over 1,000 kW, with durations between 0.1 and 5 microseconds. This has entailed detailed researches on the performance of transformer irons under the peculiar conditions of magnetisation involved, and in the construction and insulation of coils, including methods of sealing against moisture and the effects of reduced atmospheric pressure.

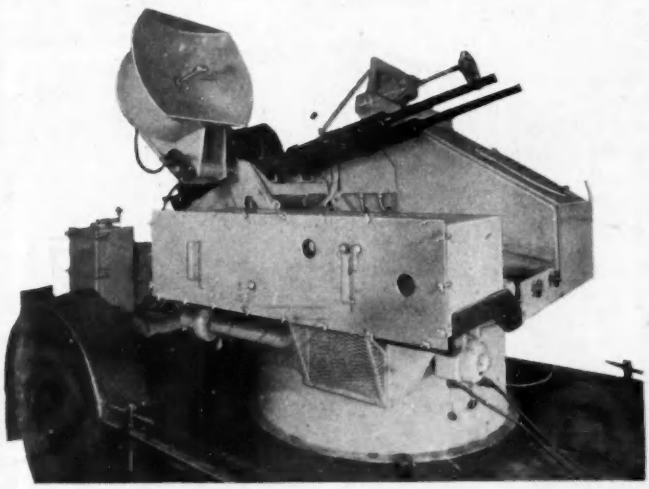


Fig. 6.—Compact range finder.

Radio Frequency Cables.

The outstanding feature in the wartime development of radio frequency cables has been the use of polythene as a dielectric. Polythene is a white translucent thermoplastic with a dielectric constant of 2.3, high dielectric strength and a power factor between 0.00015 and 0.0003, which is maintained up to the highest radio frequencies. It is available in a number of grades which are flexible over the range of temperatures met with in the severest Service uses, that is from tropical heat to the low temperatures encountered at the highest altitudes. Polythene has been used as dielectric for almost all radio frequency cables during the war. Trouble was initially experienced from

voids which occurred during extrusion and also during the subsequent cooling of the polythene covered conductor. This has been overcome by redesign of extrusion machines and the development of a special technique for cooling the cable under pressure.

For special applications requiring low capacity cables air has been used as much as possible as a dielectric. The cable shown in fig. 8 is of special interest since the five ribbed polythene supports and the surrounding tube are extruded together, giving the cable much more mechanical strength than in former designs where the two could move relatively to each other.

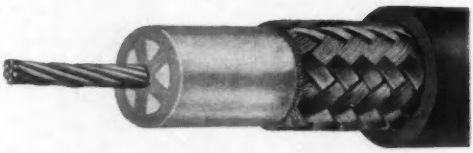


Fig. 8.—Radio frequency cable with continuous five-ribbed support.

A very low loss cable has been produced employing spaced, moulded, three-fin polystyrene supports (fig. 9). The special feature of this cable is the external sheath of welded stainless steel, which is very resistant to compression and longitudinal strain, but light in weight. The cable can be used underground or submarine without further protection or overhead without catenary support.

Radio Communication.

Aircraft Radio.

Because of the Company's unique pre-war experience in the one to ten metre band—the V.H.F. (Very High Frequency) band—it was asked to concentrate on the development of communication equipment for the R.A.F., which had to be supplied with what was then an entirely new and very reliable form of air to ground communication system.

The first V.H.F. set to be used in aircraft was a four-channel airborne equipment (TR1133), which weighed less than 70 lbs. and was developed in collaboration with the Royal Aircraft Establishment (fig. 10). This set which was used by British fighters during the battle of Britain operates in the 100-120 Mc/s band. Any of the four frequencies can be selected by a push-button, and quartz-crystal controlled oscillators ensure accurate tuning. Telephonic communication between aircraft and base, or between aircraft and aircraft, is provided with this equipment up to distances of 100 miles. Three improved versions of the TR1133 were later developed in collaboration with R.A.E.—the four-channel TR1143 which was later adopted as standard for all Allied Fighter Commands, an eight-channel equipment, and a very lightweight four-channel equipment for high altitude fighters.

The M.A.P. then approached the Company to see whether it would be possible to provide a still wider choice of channels. As a result of this request an entirely new principle of channel selection, known as the "Asac" system (Automatic Selection of all Channels), was evolved. This system enables the pilot to select any one of 336 channels merely by setting two dials to the appropriate letters. The equipment has full crystal control on each channel, but only uses three crystals. It is only half the weight of the TR1143, and incorporates a frequency modulation system as well as amplitude modulation. The aerial system evolved for use with the equipment was designed so that it operated efficiently over the frequency range without adjustment.

Police Radio and Broadcasting.

Other developments in the V.H.F. field include the continuous improvement of the single frequency Police type of equipment for two-way communication between cars and headquarters (fig. 11). The very sensitive Frequency Modulation receivers which enable large areas to be covered, inevitably amplify the weak random noises in the aerial system, so that in the absence of a signal a loud rushing noise is heard. To avoid annoyance to the user, a new circuit has been evolved which short-circuits the loud speaker except when a message is received. Work has also been done on techniques which enable communication to be maintained without interruption over very large areas.

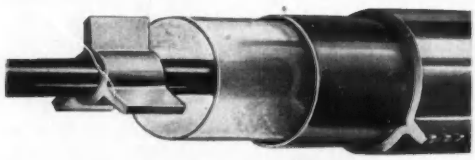


Fig. 9.—Section of a very low loss cable, which contains less solid dielectric than any other known cable.

A low power consumption receiver has been developed which enables unattended apparatus, such as lights on buoys used for night landings

of flying boats, to be switched on or off by the appropriate radio signal from a distant control point. The battery drain is kept to a minimum by means of a clock operated device which switches on the receiver for predetermined short intervals only.

Considerable exploratory work has been done on assessing the relative merits of amplitude and frequency modulation systems for V.H.F. broadcast applications.

Fig. 11.—Radio transmitting and receiving equipment installed in a police car.

Radio Communication on Centimetre Wavelengths.

The application of the shortest radio wavelengths to radio communication projects has been widely studied. At the beginning of the war there was in existence a single channel 50 cm. radio telegraph communication system, employing a magnetron transmitter which was probably the first to give performance of a standard comparable with ordinary shortwave equipment.

Later a single channel telephony equipment operating on a wavelength of about 10 cm. was developed, using the E.1210 magnetron both as transmitter and as local oscillator in the superheterodyne receiver. Amplitude modulation is not very satisfactory at these wavelengths partly because of the associated frequency modulation and partly because of the difficulty of producing linear modulation of large amplitude. Pulse width modulation, however, which was developed for this equipment proved very satisfactory, and good quality speech has been achieved over ranges up to 100 miles, directive aerials being used at both transmitter and receiver.

Similar results have been obtained with a frequency modulated triode system operating at the same wavelength.

More recently equipment has been produced for single channel telephony, with a carrier frequency of 10,000 Mc/s (3 cm. wavelength). This equipment, shown in fig. 12, has operated satisfactorily over a sea path of about 60 miles. It is arranged for direct connection to a line telephone system.

Fig. 10.—TR1133, very high frequency aircraft radio.

TELEPHONY AND KINDRED EQUIPMENT.

The majority of the large number of telephone switchboards made for the Army were designed for quick erection and dismantling, and for ease of transport were split up into easily handled, totally enclosed units. In some cases composite exchanges, having as many as 360 lines, can be made up from these switchboards. Fig. 13 shows a 200-line transportable, central-battery, manual exchange, capable of being adapted for use with any type of military or civil exchange. It has five operators' positions,

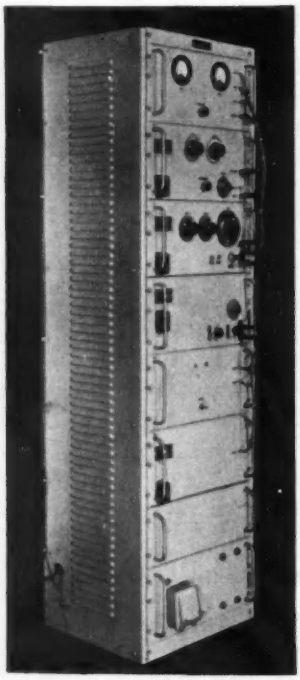


Fig. 12.—3 cm. telephone equipment with reflector removed.

though only a single operator is necessary at quiet periods.

Several thousand repeater units for amplifying speech frequencies have been made. Each unit comprises two repeaters on one panel, and each repeater can be inserted in a separate line and amplifies the signals in both directions. Apparatus has also been made which allows a telephone line to be used simultaneously for speech and for two-way telegraph (teleprinter) working. One set is connected at each end of the line and filters separate two narrow frequency bands from the speech channel for transmitting voice-frequency telegraph signals. Another type of equipment provides a speech channel and a simultaneous carrier telephone channel. The carrier frequency is 6 kc/s. for both directions of transmission, but the carrier and one sideband are suppressed in each case, the upper sideband being used for transmission in one direction and the lower sideband for the other.

Low-Voltage Relay Control System for Admiralty.

A successful low-voltage relay control system for centralised control of the circuit breakers on the electrical ring main system has been developed for the Admiralty and is being installed in our new warships. It is much less susceptible to loss of control under damage conditions than the former high-voltage system and is less bulky. The main switchboard controls all circuit breakers and shows which breakers and switches are closed, and which sections of the ring main are on. It also shows the conditions for dynamos that are running.

Fig. 13.—200-line transportable Army telephone equipment.

There are four unit switchboards each giving control of a quarter of the ring main system for use if control is lost from the main switchboard. The switchboard equipment is basically similar to that used in telephone exchange practice, but more robust in construction. The control key and indicator lamp units are plugged into the switchboard panels so that a faulty unit can be changed instantly.

Tactical Projector.

A novel device, the Tactical Projector, has been developed for the Admiralty, to replace more cumbersome methods of training escort ship personnel. The equipment projects images on a screen to represent two escort ships and a submarine, and the movements of each are separately controlled so that any required evolution can be performed. The screen represents an area 7 miles square on a scale of 10 inches to a mile. The exercise can be photographed and the developed film projected back on the screen for criticism.

Fig. 14.—Quartz crystal mounted on B7G valve base.

Quartz Oscillator Crystals.

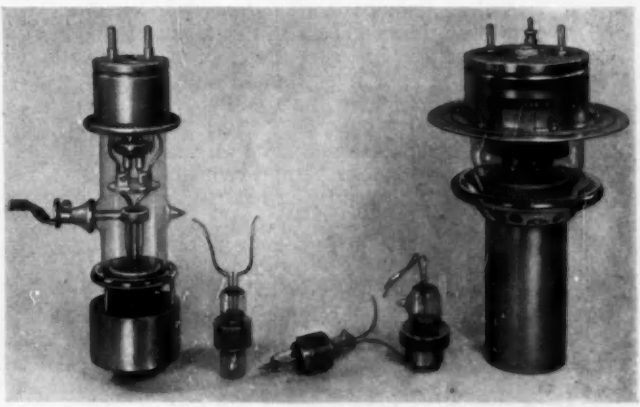
Recent developments have been stimulated not only by technical needs such as improved precision and stability of frequency, and resistance to extremes of climate, but also by the shortage and high price of raw quartz. Drastic reductions have been made in the size of plate used for high frequencies (5 Mc/s. and over). By using a metallising and solder mounting technique this has been achieved with no loss of performance as compared with the large plates between steel electrodes which used to be standard practice. It is hoped to extend this range of miniature crystals down to frequencies of about 1 Mc/s.

Much attention has been paid to producing compact and inexpensive hermetically sealed holders. Systems for mounting all types of crystal in vacuum in standard valve envelopes have been developed. For instance the high frequency plates mentioned above have been mounted in the miniature seven-pin (B7G) envelope (see fig. 14). To meet a demand for crystals to give an overall frequency accuracy of 20×10^{-6} in mobile equipment, compact thermostatically controlled crystal ovens designed to withstand tropical conditions, and the usual bump and vibration tests have been produced.

VALVES.

Transmitting Triode and Tetrode Valves.

The special requirements of Radar have called for many new developments in the field of electronics, and particularly in transmitting valves. In the early experiments before the war, the limitations of the ordinary valves developed for broadcasting, etc., soon became evident, and it was obvious that to develop the very high radio frequency power required in the pulses, two main improvements in transmitting valves would be necessary. Filaments or cathodes having much higher emission would be required and valves should be capable

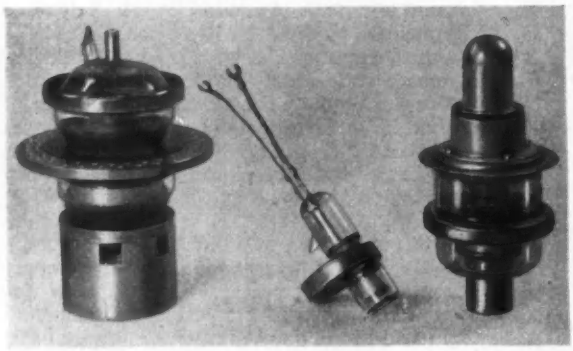


VT58 NT97 VT90 NT99 VT114

Fig. 15.—Radar transmitting valves.

of operation at much higher anode voltages.

At first the filament was increased simply by fitting larger filaments of pure tungsten wire. A little later thoriated tungsten filaments were substituted, and by this means the emission and power output were doubled and the heating power was halved. Triode and tetrode transmitting valves, employing this technique, were designed in 1938 for use in early Radar equipment. The VT58 and VT114 shown in fig. 15 are examples of valves used in ground transmitters giving peak powers up to a few hundred kilowatts at wavelengths of a few metres.



CV288 (E.1495) CV55 CV257 (E.1457)

Fig. 16.—Ultra high frequency transmitting valves.

Next came Service demands for peak powers of many tens of kilowatts at much shorter wavelengths for use in airborne and other compact equipments. A whole series of valves, specially designed for Radar, was developed to meet Service needs in this field. The series started with the "micropup" VT90, which can be seen in fig. 15, and which was widely used throughout the war by the three Services. This valve has a thoriated tungsten filament and operates efficiently at wavelengths down to 1 metre. Improvements in the design of the grid seal permitted operation at wavelengths below 50 cm., and the successful introduction of indirectly-heated oxide coated cathodes greatly increased the power output. Thus the NT99 (fig. 15) enabled compact transmitters capable of giving 200 kW at 50 cm. to be built. The power output was further increased in two ways: (1) by making still larger valves (CV240), and (2) by a study of circuit technique which resulted in methods of operating valves in parallel, even at wavelengths as low as 50 cm.

An important part of the work was the development of designs and techniques to enable the valves, which had very small clearances particularly between grid and cathode, to be manufactured by unskilled labour in the large number required by the Services.

Many valves designed specially for pulse operation are not suitable for C.W. working. Therefore the problem of producing high continuous power as opposed to pulse power had to be studied independently. Similar advances in valves for C.W. at very high frequencies have been made, and improvements in grid and anode design have resulted in power amplifiers, *e.g.* CV257 and CV288, fig. 16, which are suitable for use at frequencies up to 1,000 Mc/s. Fig. 17 shows the power output available from these valves as compared with typical pre-war types.

The modulator requirements of Radar, where energy has to be delivered to the transmitter in pulses, are conveniently fulfilled by valve devices. Vacuum tetrodes for this purpose are used to switch on and off a high voltage D.C. supply. The use of oxide cathodes to give high emission, and manufacturing techniques to give high voltage performance led to the NT100 (CV44) and CV57 valves, fig. 18, which were used in A.I. Marks VII and VIII respectively. For higher powers gas triodes were found to be more suitable, and a number of them were developed. The largest of these

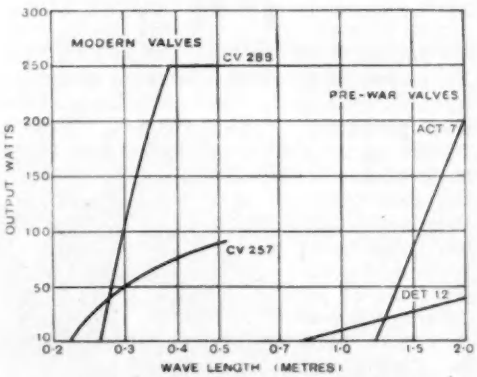


Fig. 17.—Relation between output and wavelength for modern and pre-war transmitting valves.

gas triodes, the CV12 was widely used in Radar equipments, and in particular it was used to provide the pulse modulation in the most powerful 10 cm. Radar sets. This type of valve incorporated a labyrinth grid (now known as the positive starter), which is particularly suited to the transient operation required.

Receiving Valves.

During the war the upper frequency limit of operation of receiving valves as local oscillators, amplifiers and frequency changers has been extended by a factor of approximately ten.

Two new techniques have made this possible. First, the use of disc seals, which has appreciably reduced the inductance of the leads to the electrodes. This has resulted in the valve becoming an integral part of the circuit, which for efficient operation at very high frequencies takes the form of a resonant cavity or section of transmission line. Secondly, electron transit time has been reduced by the use of very small inter-electrode spacings; in some types the grid-cathode spacing is between .002 ins. and .003 ins. Typical examples are shown in fig. 19. The triodes will oscillate at frequencies up to 3,750 Mc/s.; the CV273 gives 3 watts output at 1,000 Mc/s. and 0.5 watt at 3,000 Mc/s. The amplifier valves give power gains of about 15 decibels at 1,000 Mc/s. and 8 decibels at 3,000 Mc/s. with several decibels improvement in signal to noise ratio over a modern crystal mixer at the former frequency.

To meet the need for more efficient mixers at high frequencies the performance of various types of thermionic valves was investigated, both theoretically and experimentally. This work indicated that diodes had many advantages and a small indirectly-heated diode with closely-spaced planar electrodes, the CV58, see fig. 19, was designed for mixer use. Its low lead inductance and small size make it suitable for use in coaxial line circuits and at frequencies up to 600 Mc/s. its performance is comparable with that of a crystal.

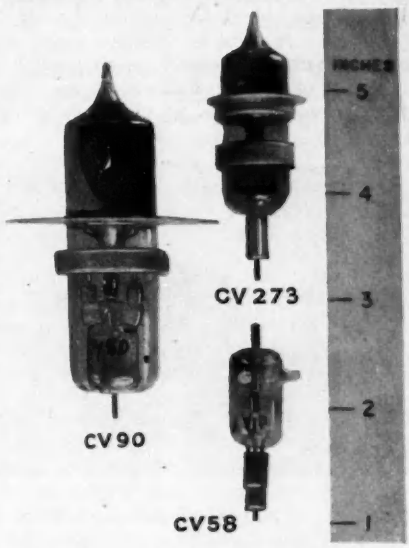


Fig. 19.—Ultra high frequency receiving valves.

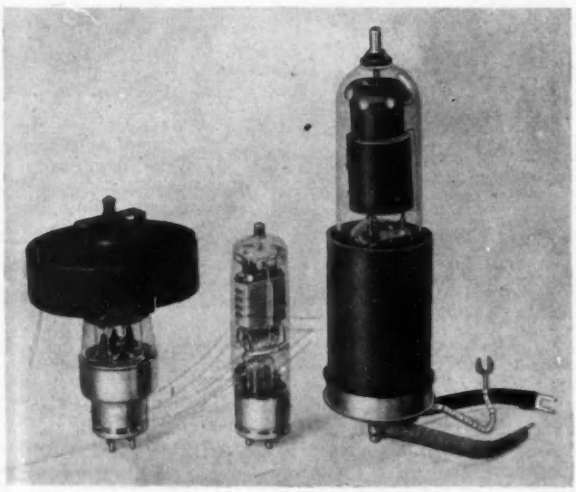


Fig. 18.—Pulse modulating valves.

The measurement of voltage at high frequency is a problem which often confronts the radio engineer. The small size of the CV58 makes it very suitable for use in valve-voltmeters for frequencies up to several hundred megacycles. It is, however, not suitable for the measurement of voltage in coaxial lines, and a special filamentary diode, the E.1199, suitable for frequencies up to 6,000 Mc/s. has been developed specifically for this work. The construction is such that errors due to lead reactance are small, and by a suitable

tuning adjustment can be removed altogether.

Magnetrons.

At the outbreak of war dull emitter magnetrons with thoriated tungsten filaments were already established for medium power C.W. operation. A typical example, the NT75 four-segment glass-envelope magnetron, has an output of 20 watts C.W. at 50 cm., rising to over 50 watts, with an efficiency of about

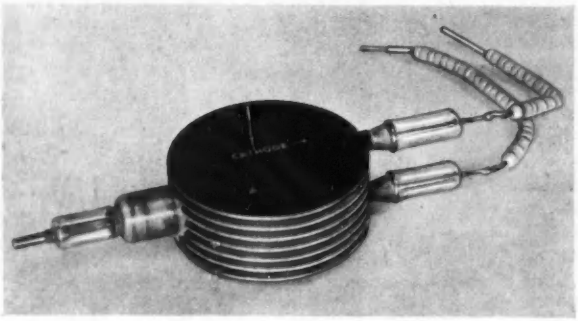


Fig. 20.—Magnetron type CV 76.

50 per cent, at longer wavelengths.

In collaboration with Birmingham University the multiple circuit copper block magnetron was developed as a practical generator of high power on centimetre wavelengths in 1940. The introduction of the oxide cathode made possible the generation of short pulses of much greater power than is possible with any other type of oscillator. By virtue of secondary emission from the cathode, an effect discovered in the Research Laboratories in 1933, the technical problem of obtaining the high peak anode currents required (which may be of the order of 50 amperes) is less difficult than in ordinary valves. Valves of this type were developed primarily to meet the urgent needs of A.I. Radar on centimetric wavelengths, and they are now used in practically all Radar equipment on the shorter wavelengths. For airborne applications in particular it was important to design the valve in compact form so that magnets of relatively small weight could be used. The gold seal technique, previously developed in the Laboratories, was of great value in achieving this, and the resulting design was simple and well adapted to production in the large numbers subsequently required. Two examples of valves of this type which have been widely used in Radar equipment to generate powerful pulses lasting one or two microseconds are the CV76 (fig. 20) and the CV214 (fig. 21). The CV76 operates at a wavelength of about 10 cm. and is capable of a peak power output of 500 kW with an efficiency of 55 per cent. The CV 214 is designed for operation in the region of the still shorter wavelength of 3 cm., and has an output of 45 kW with an efficiency of 30 per cent.

Early in the war a different type of multiple circuit magnetron, also employing an oxide cathode, was developed as a low-power source for centimetre wavelengths. In this the resonant system radiates its output through the glass envelope directly into a waveguide. One such valve, the E.1210 (fig. 22), operates at about 9 cm. wavelength with an output of 0.5 watt for an anode voltage of 350 volts. This valve has a very long life and has been employed both as transmitter and as local oscillator in communication equipment.

Silicon Crystals.

In 1940 the need for satisfactory mixers and

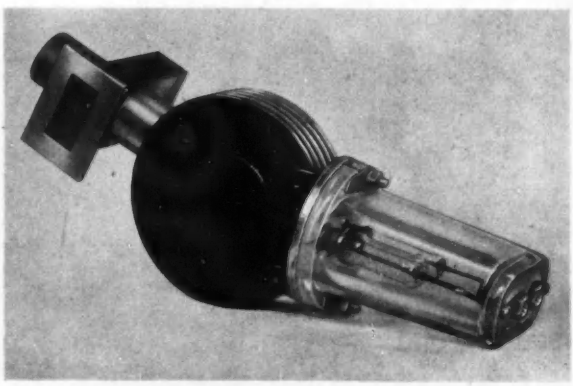


Fig. 21.—Magnetron type CV 214.

detectors for centimetric Radar became extremely pressing. Special point contact crystals appeared to offer considerable promise for these purposes, and intensive work on them was

started. Trials of a large number of known as well as of previously untried rectifying point contacts showed that a tungsten point on a silicon crystal had considerable advantages. As the form of crystal detector with adjustable "cat's whisker," which had been used in the

Fig. 22.—Magnetron type E.1210.

early days of radio, was quite impracticable under Service conditions, a new totally enclosed "cartridge" crystal detector was developed. When once adjusted this was wax-filled and would then withstand rough treatment without change of characteristics. Fig. 23 shows a crystal cartridge together with the parts prior to assembly.

The next problems were to meet the continual call for higher sensitivity and to provide crystals which would withstand the surges set up by the high power pulsed transmitter. Research on the physical state of the crystal surface and on means of modifying it, combined with investigations on the metallurgical and chemical aspects led to the development of a type of crystal having outstanding resistance to burn-out. It was also found possible to produce crystals whose surfaces were so uniform that good characteristics were obtained immediately on making contact with the tungsten point, thus eliminating the searching over the surface during assembly which had previously been necessary.

Gas Discharge Devices.

There have been many applications of small gas discharge devices as voltage stabilisers, as indicators of power and standing wave patterns in waveguides, as trigger tubes for modulator circuits, and as protective devices in Radar equipments.

In Radar systems, particularly those using a single aerial for transmission and reception, a device to protect the first valves of the receiver is required. For this purpose many gas discharge tubes have been designed. At 45 and 200 Mc/s. gas-filled diodes and mercury or argon filled tubes with tungsten electrodes were used, and for 1,200 Mc/s. a tube which fitted in a tunable coaxial line was developed. At higher frequencies, 3,000 Mc/s. and 10,000 Mc/s., the discharge tube either embodied its own tunable resonator or was itself the resonator. Fig. 24 shows a gas switch designed for operation at approximately 10,000 Mc/s.

The protective device is coupled to the transmission line from the aerial to the receiver, and when the transmitter fires, the discharge tube strikes, puts a low impedance across the line, and limits the power passing to the receiver. Priming electrodes have still further reduced this power level. The tube must de-ionise rapidly after the transmitter has fired in order that the blind area or "minimum range" of the system may be kept as small as possible. The speed of de-ionisation has been increased by the addition of oxygen or water vapour to the gas in the tube. Other types of tube with resonant electrode systems have been developed for short circuiting the transmitter arm of a common aerial feeder system at a suitable point so as to decrease the proportion of reflected signal from the target which does not reach the receiver.

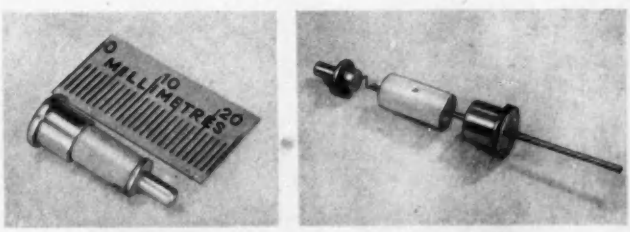


Fig. 23.—Silicon crystal cartridge with parts prior to assembly.

CATHODE RAY TUBES.

Prior to and during the war considerable research and development work on cathode ray tubes for Radar has been carried out at the Research Laboratories. This has resulted in the production of a range of Radar tubes of

Fig. 24.—Gas switch for operation at approximately 10,000 Mc.

specialised types, a selection of which is shown in fig. 25. During the war the Lamp Works have handled forty different types in all, and of these, twenty were in production at any one time. Usually these tubes had special fluorescent screens with a long "memory," which made heavy demands on the power of the electron gun. Of special interest, is the 12 in. electrostatic tube on the left hand side in fig. 25. Development on this tube started in 1938, and over 50 varieties of fluorescent screen were investigated, in order to obtain optimum performance. A special electron gun of some four times the normal beam intensity, was required to excite the screen "memory" when the tube was used in the existing equipment, and this was provided as well as an improvement in focus quality. Satisfactory tubes were being delivered by the summer of 1939 to the Chain Stations, which subsequently played such an important part in winning the Battle of Britain.

In the early stages of the war, the production effort was mainly required for the larger diameter tubes (9 in. and 12 in. diameter), used by the Navy and the defensive ground stations. The demand for tubes suitable for airborne equipment grew steadily, and eventually resulted in the use of fully automatic processing on some designs. In these tubes, ranging in diameter up to a maximum of 6 in., advantage was taken of the relatively short life required to increase the performance of the tubes, thereby saving power, space and weight in the aircraft. On the right hand side of fig. 25 will be seen the most modern Radar cathode ray tube produced for the H_2S equipment, with which Bomber Command had been administering such effective night raids on Germany.

At the present time, the development of a range of cathode ray tubes for television is in hand. The wartime effort has not contributed

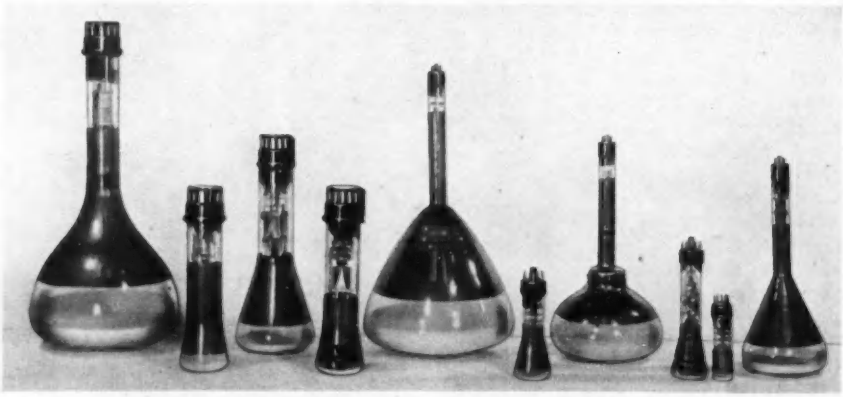


Fig. 25.—Cathode ray tubes ranging in height from 2 ft. down to 6 inches

anything directly to television tubes, mainly because of the preponderance of electrostatic types required for Radar requirements. There is no doubt, however, that the improvements in manufacturing techniques, and increased design knowledge available, will result in cheaper and better tubes being available.

MARINE ELECTRICAL EQUIPMENT.

AIRCRAFT CARRIERS.

Aircraft Lifts.

The G.E.C. has an outstanding record in the matter of aircraft carrier equipment which dates back over 20 years to the time when, in collaboration with the Admiralty, aircraft lifts were developed for H.M.S. *Furious*, *Courageous* and *Glorious*. The Company's services were again called upon in connection with the design and manufacture of aircraft lifts, bomb and torpedo lifts, shell hoists and conveyors for the first aircraft carrier designed as such, the famous *Ark Royal*. Following this tradition, it is worthy of note that Fraser & Chalmers Engineering Works designed and installed all the aircraft lifts required by the Royal Navy during the war.

The platform of an aircraft lift is generally longer than it is wide, and the load is always run on or off over its end

Fig. 27.—A view of H.M.S. Glorious from the deck of H.M.S. Courageous.

Fig. 26.—Hawker Ospreys on the flight deck of H.M.S. Ark Royal.

in the direction of its length. It was therefore considered more practicable to arrange to prevent movement in the horizontal plane only, by means of four guides near each corner preventing athwartship motion, and two guides preventing fore-and-aft motion, one on each side of the platform.

The platform is so suspended as to maintain the level trim of the lift, suspension points being necessary near each corner, both to reduce the cantilever stresses as the load runs over the edge of the platform and to maintain complete stability. A number of intermediate suspension points are also provided along each side at opposite ends of the

main cross girders. This arrangement gives a minimum depth for the pit required beneath the lower stopping level thus leaving valuable deck space below the pit available for use. All suspension points must be driven at the same speed and connected by a system of adequate stiffness to maintain them at the same level during all operations of the lift.

On the original *Ark Royal*, where the power was hydraulic, each lifting point had its individual cylinder and synchronisation was arranged hydraulically, but roller chain suspension was decided upon, largely on account of its freedom from stretch. Therefore in *Illustrious* and other ships of this class, where electric power was available, the use of roller chains running over sprockets driven

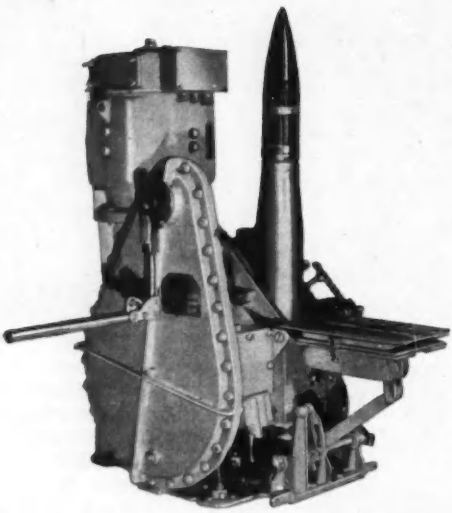


Fig. 28.—Hand winding gear for battleship shell hoist.

from a "ring main" of shafting satisfactorily solved the problem of synchronisation.

The rapid operation of these lifts, which are called upon to handle total moving masses of the order of 80 tons, demands accurate stopping at deck level with no "inching." A system of Ward Leonard control was therefore adopted which also permits low "decking" speed. In some cases four stopping levels are required, and this was satisfactorily dealt with by automatic electric decking.

Later, when urgent Service requirements necessitated more rapid construction, the use of steel wire ropes and drums driven from a common shaft was substituted. Such installations proved quite satisfactory, and eleven lifts of this type were developed.

An interesting feature of these lifts is the means adopted to close the flight deck opening when the lift is in position. In some cases movable rubber sealing strips were used, the pressure applying the seal causing the strips to bulge upwards against the edge of the opening, thus completing the seal. Hydraulic pressure has been used for this purpose, or a small electric motor has been employed operating through gearing and a system of toggles. An alternative method has been to arrange a deep gutter round the platform and to carry away water to fixed drainage pipes by means of deflecting chutes, moved automatically into position as the lift approaches the flight deck.

In addition to aircraft lifts, many special purpose lifts were designed and installed in naval vessels, such as bomb and torpedo lifts for aircraft carriers, lifts for large tank landing craft and mine lifts, all of which involved unusual points of interest.

In one case, for instance, the guides had to be telescoped to clear the deck space when the lift was not in use, in other cases the lift served the flight deck through openings which were closed by hinged covers when the lift was not required. One such instance involved the moving of a large plate of substantial thickness from the hole in the deck to a vertical position clear of the lift by an electric motor driving through gearing and a harmonic crank motion, a special feature being a vertical motion of about 4 ins. to get the plate clear of the deck before beginning to turn it into its vertical position.

The various installations involved flashtight shutters against bomb blast, gastight shutters against petrol fumes and many other mechanical features for which electrical control systems were developed which combined a high measure of interlocking with a minimum of contactor gear. Operating switches in the vicinity of petrol vapour, or in similar positions, were made flameproof, and many certificates for such gear were obtained from the Mines Department. The whole of the electrical equipment comprising motors, contactor gear, deck selecting and control switches, was designed to comply fully with the requirements of the standard Admiralty shock test. In all, more than 50 installations were made involving seven main types.

Ammunition Hoists and Conveyors.

Ammunition hoists were constructed and installed in aircraft carriers, escort vessels, a

depot ship, a cruiser and in a large number of destroyers, the total supplied exceeding 270. The destroyer hoists were developed to meet the demand for a simple, light-weight, readily installed ammunition hoist (fig. 28). They embodied full watertight protection, a simplified power-to-hand change-over, and full hold-back and embarking features. The mechanical friction clutch, pedal operated, previously employed with a continuously running motor, was omitted, and a contactor type timing starter, also pedal operated, was developed, the motor being started and stopped as required. This method of control proved so successful that it has since been adopted as standard practice for ammunition hoists, the clutch being no longer used.

Ammunition conveyors of both open and watertight types have been designed and installed, the number exceeding 45 units. The conveyor comprises a number of small carriers, with Ferodo or Balata facings, running on rollers and connected by chains, with an arrangement of running and return tracks forming the complete system. In the case of the watertight conveyors, where the ammunition travels in closed horizontal trunkways, a photo-electric cell device was employed to stop the conveyor should the unloading party fail to remove the delivered round in time to allow the next one to arrive in the delivery tray. A single photo-cell equipment, which had the merit of simplicity, was employed in conjunction with a mechanical clutch device driven from the conveyor, and this allowed the advancing round to close up to the delivered one for the permissible distance. Had the latter not been removed from the light ray before this point the conveyor was automatically stopped.

Other equipment produced for the Admiralty included a large amount of Asdic gear, approximately 50 per cent of their total requirements, for which special shops were laid out; water-tight submarine doors, spray shields for gun mountings, various types of rocket projectors, and gun mountings.

Equipment for Docks.

Seven large dock electrification schemes have been undertaken, comprising three floating docks for the Admiralty and four graving docks for Cape Town, Sydney, East London and Colombo.

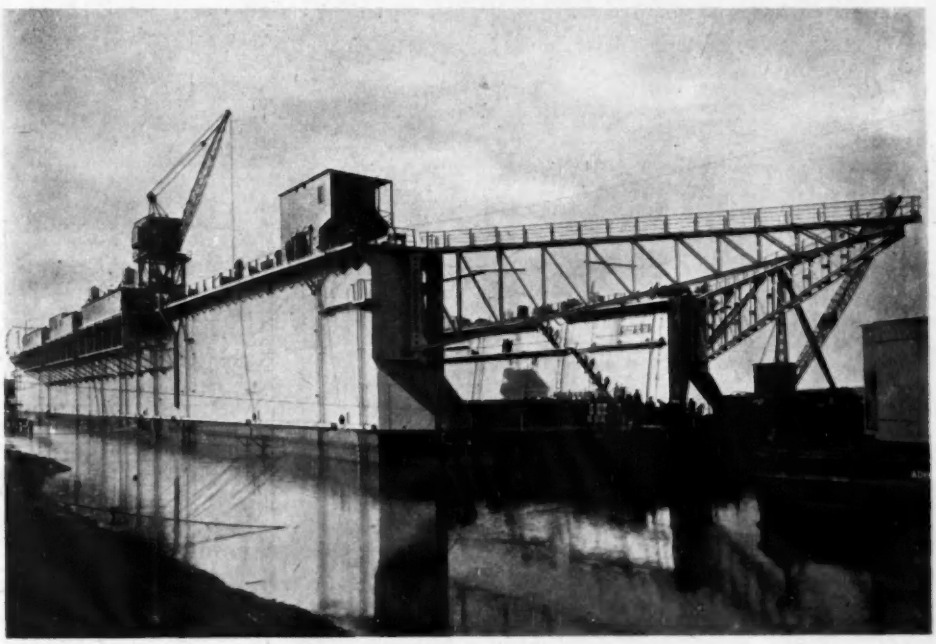


Fig. 29.—15,000 ton Admiralty floating dock constructed at Durban.

The first of the floating docks to be completed, known as A.F.D.XXXIII, is a reinforced concrete structure capable of handling small craft up to 1,000 tons, and was designed to lift vessels of this displacement, having a mean draught of 14 ft., in 1½ hours. For this purpose two pumps are provided, each driven by a 47 h.p. vertical spindle motor capable of delivering 25 tons of sea water per minute against a mean head of 16 ft.

The second floating dock to be finished, known as A.F.D. XXXI, is a cruiser dock having a steel structure in seven sections. It is capable of lifting a vessel displacing 15,200 tons, with a mean draught of 25 ft., in 4 hours. The length of the dock is 584 ft., with a breadth overall of 144 ft. Four 95 h.p. vertical spindle motor-driven pumps each deliver 53 tons of sea water per minute against a mean head of 17½ ft. A view of the dock is shown in fig. 29.

The third and largest of the floating docks to be undertaken, A.F.D. XXXV, is a 50,000 ton dock capable of handling any capital ship in the world. The overall length of the dock is 857 ft., and its breadth 185 ft. It is capable of lifting a 50,000 ton vessel in four hours, for which purpose seven pumps are installed driven by vertical spindle, 3,300 volt, slipring induction motors varying in size from 105 h.p. to 360 h.p., and delivering a total of 30,000 tons of sea water per hour against a mean head of 30 to 36 ft.

In the case of this contract the Company were main machinery contractors, and were responsible for the complete equipment of the dock, including boiler plant, three 1,000 kW geared turbo-alternators, condensers, evaporators, all switch and control gear, Diesel-engine sets, fire pumps, domestic heating, lighting, workshop machines, fresh and distilled water pumps, all cable work, and all the pipework required for the steam, air and water installations. The magnitude of the work involved was greatly increased by the fact that no consulting engineers were appointed. The company was also responsible for the erection of the entire plant in the hull of the dock at Bombay.

The electrical equipment installed in the two smaller docks differs only in degree of magnitude from that of the 50,000 ton capital ship dock. Each dock has been equipped with

Fig. 30.—Captain Cook Graving Dock, Sydney, N.S.W.

its own generating plant, auxiliary motors, and switch and control gear, in addition to lighting and heating schemes.

Of the four graving docks, two have been officially opened and two are still in course of construction. The first to be opened was the Captain Cook Dock at Sydney, New South Wales (fig. 30), which is one of the largest graving docks in the world, being 1,096 ft. long and 147 ft. 7½ ins. wide. The main contractors were Gwynnes Pumps, Ltd., and the electrical equipment, comprising main pump motors and auxiliary motors, main generators, main switch gear, cables and a large amount of miscellaneous gear, was supplied by the G.E.C.

The Sturrock graving dock at Cape Town was opened in September, 1945, and is also capable of handling the world's largest ships. It is 1,171 ft. long by 148 ft. wide.

The Sturrock Dock, named after the Hon. F. C. Sturrock, M.P., Minister of Transport, Union of South Africa, who was chiefly responsible for initiating the scheme, enables the Port of Cape Town, long known as "The Tavern of the Seas," to take its place among the great ports of the world. The main contractors were Gwynnes Pumps, Ltd. The dock pump house equipment comprises three 1,200 h.p., 2.2 kV, 273 r.p.m. salient pole synchronous induction motors, driving horizontal spindle de-watering pumps. The motors are connected through 950 kVA step-down transformers to a 12 kV, 350 MVA solenoid operated, single busbar metalclad switchboard, which controls the two incoming feeders from the external 12 kV supply. Complete automatic control of the main pumps and valves is given from a central control desk, the drainage pumps being automatically controlled from

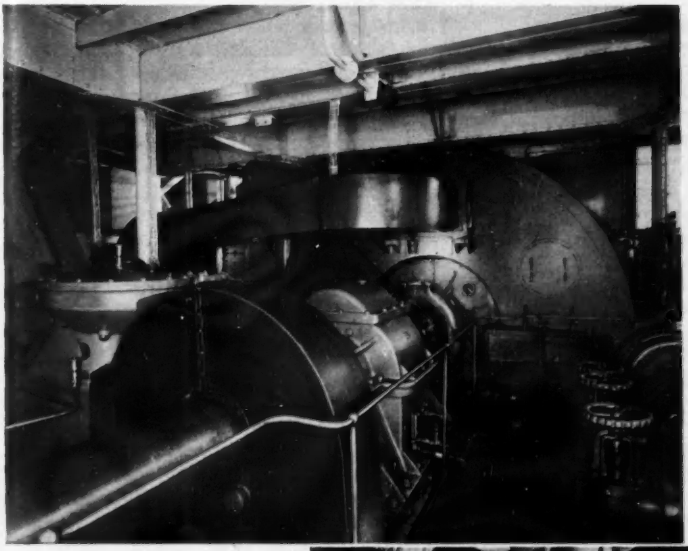


Fig. 31 (*above*). **The 6,800 s.h.p. synchronous propelling motor in the "Empire Byng."**

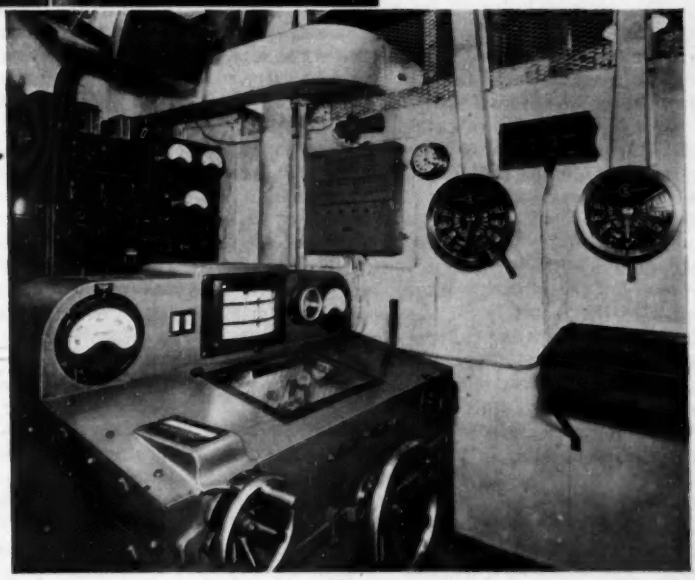


Fig. 32 (*right*). **Propulsion control equipment.**

a smaller desk. A large mimic diagram of the dock filling and draining system provides a continuous indication of the position of all valves, showing which motors are running and which valves are open or closed. Pumps and valves operate in a certain sequence by means of the "Gwynnes" control system. The dock pump house also contains a large number of induction motors ranging from 1½ h.p. to 230 h.p., driving drainage pumps, seepage pumps, etc.

An underground sub-station situated at the head of the dock is equipped with two 525 kW, 220/110 volt D.C. generators, giving a power supply to vessels using the dock. Each is driven by a 760 h.p. 2.2 kV synchronous induction motor connected to the 12 kV supply through 625 kVA step-down transformers. Control of the incoming 12 kV supply, also of the outgoing feeders to the pump house, is provided by a 9-unit single bus 350 MVA solenoid operated metalclad switchboard.

All the cables for the pump house and sub-station, sub-distribution boards, telephones, ventilating plant, automatic fire extinguishing plant, water level indicating gear, and lighting equipment, were also supplied, while all the motors, totalling approximately 6,400 h.p. in capacity, switch and control gear, are below ground level, and are fitted with internal heaters to prevent condensation.

Electrical Propulsion Equipments.

The great volume of work undertaken for the Admiralty is of too comprehensive a nature to be described in detail, but some idea of the magnitude of the work may be gained from the following statements.

A total of 43 sets of propelling equipments and 14 sets of propulsion switch and control gear were completed for submarines. Over 450 motors and generators ranging in capacity from 60 kW to 500 kW were constructed, and over 50,000 ship ventilating fans have been supplied for engine room ventilation for all classes of warships. Every aircraft-carrier built in this country for the Royal Navy has been equipped with motor-generators, motors and control gear for operation of aircraft lifts and bomb hoists, and many with electric apparatus for shell hoists.

Particular interest attaches to the electrical propulsion equipment of four heavy-lift cargo vessels, the order for which was received in 1943. The ships were built by the Greenock Dockyard, and engined under the management of J. G. Kincaid & Co. Single-screw propulsion machinery is installed in each vessel, comprising main turbo-alternator, D.C. generators, propulsion motor and control gear, together with numerous engine room auxiliaries.

The synchronous propulsion motor (fig. 31), is rated at 6,800/7,500 h.p. at 115 r.p.m., and is supplied by a turbo-alternator giving a maximum output of 5,760 kW at 3,096 r.p.m., 51.6 cycles, or, normally, 5,220 kW at 3,000 r.p.m., 50 cycles. The auxiliary 400 kW D.C. geared turbo-generator supplies power at 220 volts.

The control gear seen in fig. 32 comprises: (1) a steel cubicle housing H.T. main reversing switch, earthing resistance and circuit breaker, and instrument transformer, the copper strip connections to the motor and alternator being accommodated in steel trunking, and (2) a control desk of simple design enclosing the low tension D.C. switches and carrying only essential instruments.

Manoeuvring is effected by three controls, namely: (*a*) a hand lever actuating the H.T. direction switch through an oil servo-operated gear, (*b*) a large handwheel which carries out the starting sequence by direct mechanical operation, and (*c*) a smaller handwheel controlling the turbine speed. These controls are mechanically interlocked to prevent incorrect handling. The electrical circuit is extremely simple, the small wiring particularly being reduced to a minimum. In this connection it is of interest that the ship can operate with only one small wiring circuit.

A low tension D.C. switchboard controlling the excitation is so placed as to be easily seen from the starting platform.

The first ship completed her trials in May, 1945, and the second in November of the same year. Both are now in commission.

Propulsion Units for Lifeboats.

At the request of the Ministry of War Transport, a battery-driven electric propulsion unit for steel lifeboats on tankers was developed.

The purpose of thus equipping the lifeboats was to give the crew every possible chance of getting clear of the blazing fuel floating on the surface of the sea, in the event of the tankers being torpedoed or bombed and set on fire.

Should this occur and the order be given to abandon ship, the crew would, if possible, take to the boats while there was still some way on the ship, but it would be fatal to cast off unless there were a good chance of getting the lifeboat clear of the flames. The provision of a propulsion unit was thus of prime importance in saving the lives of the crew.

After many experiments, it was found that

a fully loaded lifeboat, weighing seven tons, could be propelled at a speed of over 3½ knots by a 1½ h.p. motor running at 4,000 r.p.m. and driving a 400 r.p.m. propeller shaft through 10 to 1 reduction gearing.

The motor was wound for 24 volts, and supplied from two standard 12 volt car type batteries, the capacity of which was sufficient to drive the lifeboat for a distance of 4 to 5 miles. Ahead and astern running were provided by a simple changeover switch, with a second interlocked switch to ensure that the motor field was closed first. The reduction gear was fully enclosed, with oil bath lubrication, and the unit was coupled to the propeller shaft in such a way that it could be easily disconnected, and, if necessary, jettisoned with the battery to make more space and reduce the weight.

The boat and propulsion units successfully passed the very stringent tests imposed by the Ministry.

Anti-Submarine Devices.

A particularly important, though relatively small, part of the work of The Express Lift Company, Ltd., has been concerned with submarine detection, and it is interesting to recall that their connection with this branch of defensive warfare dates back to the war of 1914-1918 when, in 1916, they designed and manufactured the original hydrophones.

In 1939, when the gravity of the under-sea menace became fully apparent, work on submarine detection apparatus was resumed, and since then many hundreds of improved devices have been produced, reference to which has already been made on page 19.

"Degaussing" Equipment.

The use of the magnetic mine by the enemy introduced a new weapon of war, which had it not been quickly countered, would soon have starved this country of vital war supplies. While the method of combatting the menace of the magnetic mine was one of the outstanding achievements of the war, and was soon discovered under conditions involving great personal risk, the application of the necessary protective measures to thousands of merchant ships presented a formidable problem. As is now well known, the magnetic mine is triggered by a relay sensitive to the vertical component of a ship's magnetic field, which is partly permanent, partly induced. It is therefore difficult, if not impossible, to neutralize this by any single measure since, among the variable factors, the induced part of the ship's magnetic field varies with latitude and reverses in direction on crossing the equator.

One way in which neutralization can be effected is by the use of a suitably-excited demagnetising coil surrounding the ship in a horizontal plane. The excitation of the coil will have to be varied according to latitude and ship's head in a manner which has been specified by the Admiralty. For a large ship a single coil is insufficient. It must be subdivided to deal with the various superstructures in detail; for example, separate coils would be required for the forecastle and quarter-deck in addition to a main coil, each coil having its own control equipment. Thus, for a large ship, the power requirement is high enough to warrant the use of a separate motor-generator set.

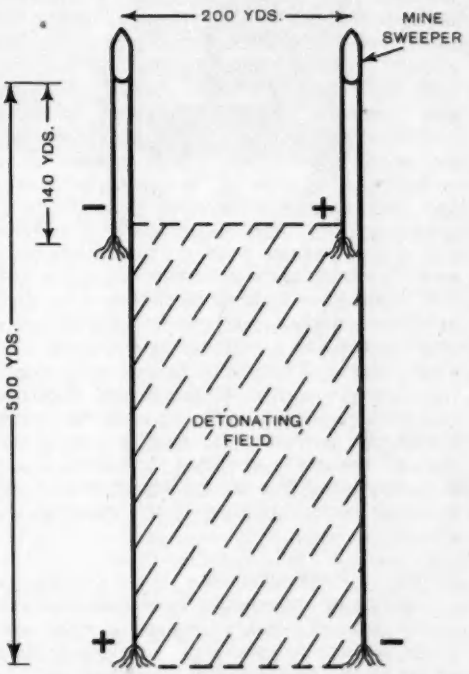


Fig. 33.—Diagram of operation of minesweepers clearing magnetic mines.

The Company accordingly designed and manufactured to Admiralty specifications a standard "degaussing" unit suitable for supplying current to individual coils. Each unit consisted of a 12 kW motor-generator driven by a 22 h.p. motor giving an output ranging from 12 to 60 volts, 350/600 amps. In the past, difficulty had been experienced with

heavy current low voltage machines in that the various brushes did not share the current equally, with the result that some of them were liable to overheat. This was overcome by a patented method of insulating the individual brush boxes so that the whole current flowed through the flexibles and not through the intermediate contact between the brush and box. The control gear, mounted in a steel cubicle, comprised a line contactor with a drum starter for the motor, together with a motor operated reversing potentiometer regulator for adjusting the generator output current. The controls for three of these units, each associated with a coil, were grouped on a small panel for mounting in the bridge or chart room. The panel carried centre-zero ammeters for each coil, centre-zero voltmeter and selector switch, and the necessary push buttons for adjusting the generator excitation through the motor-operated regulators.

A large number of merchant ships and warships were equipped with apparatus of this type.

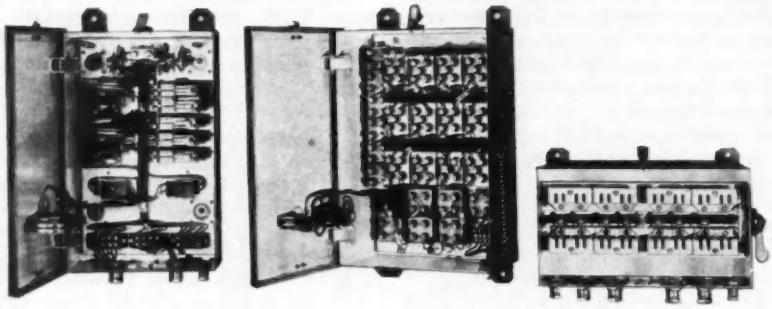


Fig. 34.—"Slave" gear pulse time controller.

Magnetic Mine Sweeping.

The obvious alternative to neutralization of ships' magnetic fields was to destroy the mines *in situ* by producing a magnetic field astern of the minesweeper employed on this work, the field being sufficiently strong to affect the operating mechanism inside the mine and explode it. It was essential, of course, that the minesweepers themselves should be effectively "degaussed."

Two minesweepers were usually employed as a unit on this class of operation, steaming abreast a cable's length apart (fig. 33). One sweeper was designated the "master" and the other the "slave." Each sweeper trailed behind it in the sea two buoyant cables, one short and one long, insulated to within a few feet from the ends which were divided up to form tails. It was arranged that during sweeping operations the two long cables (and in the same way the short cables), carried current of different polarity, thus creating a magnetic field between the cables, shown shaded in the diagram (fig. 33), the strength of which depended on the current flowing between the cables. In order to render the magnetic field more effective, current was sent through the cables in a series of heavy pulses, the two sweepers simultaneously transmitting pulses of opposite polarity. The magnetic field so produced was sufficient to detonate any magnetic mines within its influence.

Each sweeper was equipped with a Diesel-engine driven D.C. generator capable of giving a current of 3,000 amperes at 95 volts for a period of 5 seconds. A large number of these generators was supplied for installation on mine sweepers during the war. A heavy flywheel was fitted to each Diesel set and provided 75 per cent of the energy demanded by the generator during the 5-second period when it was on load. The 5-second load period was followed by an off-load period of 25/55 seconds, during which time energy was being stored in the flywheel ready for the next load period. A fluid coupling was inserted between engine and generator to permit easy starting.

The impulses were controlled, either by hand or, more usually, automatically, the control gear consisting in the automatic type of a line contactor closed by a time switch and connecting the generator armature to the buoyant cables. At the same time the generator field was strengthened. An automatic regulator, current controlled, governed the field strength

of the generator and ensured that the current output of the generator was maintained at a constant level in spite of the slowing up of the Diesel engine during the 5-second pulse. This was an important factor as it was essential that the current pulses had a square wave shape. At the end of each pulse the current in the buoyant cables was reduced to zero by removing the excitation from the generator.

A condenser timing mechanism was developed, (fig. 34), to control the action of the minesweeping trawler switchgear. The device produces a definite pulse time of 4.5 seconds at 20, 30, 36 and 60 second cycles, and can also be transferred to dual control to produce alternate pulses of opposite polarity.

The timing is obtained by the use of Post Office 3,000 type relays and electrolytic condensers, which are switched to enable any pre-determined capacity to be connected to suit the timings required. By the use of tapped condensers the gear can be calibrated to produce pulse periods of 4, 4.25, 4.5, 4.75 and 5 seconds within the limits of plus or minus 0.1 seconds, and at 20, 30, 36 and 60 second cycles within the limits of plus or minus 0.5 seconds.

The units can be switched either as a "master" unit or as "slave" units which follow automatically all the operations of the "master," thus enabling a number of trawlers steaming abreast to keep in step and sweep simultaneously over a large area. "Slave" control is effected by a sensitive relay which responds to the electrostatic charge in the sea brought about by the pulsing of the "master" instrument in the leading trawler, and is so controlled that when pulsing under dual control the "slave" gear can, in no circumstances, produce an opposing pulse. In any number of trawlers engaged in mine sweeping, each controller thus keeps in step with its nearest companion.

The apparatus comprises two units, one containing the relay equipment with rotary switches for "master" or "slave" control and for dual or single pulsing, while the other incorporates the condenser timing gear and rotary switches controlling "pulse" and "pulse period" timing. A supplementary unit was also designed, taking the form of a seven pole change-over switch, to enable the gear to be switched "Condenser Timing," "Off" or "Hand Control."

The plate on which the relays are mounted is fitted with sponge rubber gaskets by which the assembly is supported within the cabinet, thus providing an effective shock-proof mounting enabling the relays to function consistently and accurately whilst being subjected to the violent shocks and vibration associated with mine sweeping activities.

Wave-making Machine for Admiralty Test Tank.

The electrical drive and control of a wave-making machine, manufactured by Robeys, Ltd., of Lincoln, for installation in the Admiralty model ship testing tank at Haslar, Portsmouth, has several points of interest. The machine is designed to set up controlled wave systems, and is driven by a 40 h.p. 220 volt D.C. motor. In designing the electrical equipment it was essential that the motor should accelerate as quickly as possible to an accurately pre-set speed, as the time available for tests on the models in the tank was limited by the reflection of the wave-trains from the far end of the tank. The duty required of the motor was that at every 10 revolutions the load varied from about 2½ times full load as a motor to ½ load feeding back as a generator. The variations in speed had to be kept low during this cycle. The maximum power output occurs at low speed and decreases rapidly as the speed increases, as the energy required to produce waves of small amplitude and high frequency is much less than that required to produce waves of large amplitude and low frequency.

The control gear installed consists of a timing starter to accelerate the motor to its low speed of 400 r.p.m., and a motor-operated shunt regulator to give and maintain speeds between 900 and 1,200 r.p.m. In order to pre-select and maintain accurately any desired speed, an electronic speed-control gear of the voltage-balance type is incorporated. In this gear a voltage derived from an accurate tachometer generator is balanced against a steady reference voltage, or any selected fraction thereof. Any difference is detected and amplified, and is used to control the position of the main shunt regulator. The necessary anti-hunting and sensitivity controls are provided.

The installation was completed in November, 1943, and proved capable of maintaining speed within the specified 2 per cent, in spite of the cyclic irregularity of the load.

Hydrostatic Switches.

Over 50,000 hydrostatic switches have been produced for the Admiralty of various types which, although differing in construction, all function on the same principle. The switches are inserted in sea mines, their purpose being

to complete certain electrical circuits inside the mine when the latter is dropped into the sea, the pressure of the water upon the switch rendering the mine "alive." The outer casing of the switch contains a central moving spindle and rubber diaphragm, to which the moving contact assembly is attached. The moving contacts are held away from the fixed contacts by means of a plug made of material soluble in sea water. The soluble plug is shrouded in a protective cover which is removed just before the mine is dropped into the sea. After

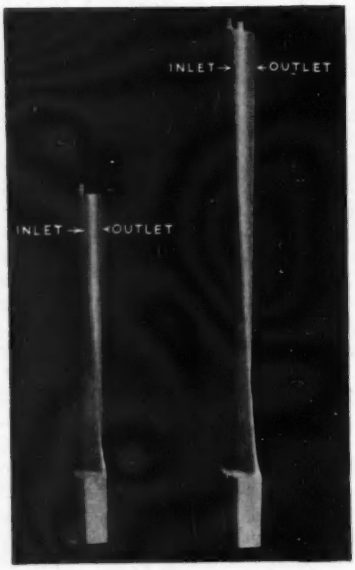


Fig. 35.—Turbine blading with degree of reaction increasing from root to tip.

a certain interval—long enough for the mine-layer to have continued steaming to a safe distance—the plug dissolves, allowing the central spindle to be depressed by the water pressure on the rubber diaphragm. The electrical circuit inside the mine is then completed, making it "alive." A feature of the switch is that should the mine break away from its mooring, the electrical circuit is broken and the mine rendered safe.

GENERAL ENGINEERING.

Steam Turbines, Turbo Blowers and Turbo Compressors.

Since 1935, Fraser & Chalmers have used, for the larger steam turbines, blading in which the degree of reaction increases gradually from root to tip ; the inlet angle of the moving blade increases gradually towards the tip, while the outlet angle gradually decreases (fig. 35). In recent years the use of this type of blading has been extended to small high speed turbines.

With increasing steam pressure the weight of steam in the space between the admission control valves and the first nozzles increases ; if load is taken off suddenly this steam may cause an unduly high speed rise. To reduce such a risk the control valves are now located in the admission belt of the casing instead of in a separate steam chest, the space between the control valves and the first nozzles being in this way reduced to a minimum. For high steam temperatures the control valves are arranged symmetrically to ensure uniform temperature distribution around the admission belt. In order to minimise still further the speed rise of large turbines when load is suddenly taken off there is incorporated in the ordinary governing an electrical "lost load" relay, actuated by the loss of load, which closes the control valves much more quickly than does the speed governor, hence it reduces the momentary speed rise and ensures that the turbine does not reach the speed at which the emergency governor would trip the control valves. After a short period of time the relay re-establishes the normal position of the governor gear, the somewhat slower speed governor then taking complete charge of the turbine speed.

The governing of pass-out turbines has been improved by the provision of complete compensation. A double pass-out turbine, for example, has three sets of control valves :—

(*a*) For steam admission to the first nozzles.

(*b*) After the first pass-out.

(*c*) After the second pass-out.

Any change of load tends to change the speed when the speed governor intervenes by acting through relays and a system of levers on all three sets of valves. Any change of pass-out quantity in any pass-out causes a pressure change at that pass-out ; a pressure responsive device intervenes and actuates all the three sets of valves. Any one change in load or pass-out quantities, or any combination of these changes, results in all three sets of valves being moved into the position corresponding to the changed condition.

When a turbine is stopped a temperature stratification gradually develops in the casing, the temperature on top being higher than at

the bottom. As a result of this stratification the shaft bends upwards (towards the higher temperature).

Should the turbine be started up in that condition, vibration and eventually damage might occur. In moderate temperatures it is sufficient to roll the rotor slowly by steam for some time before running up to speed. In the case of higher temperatures and longer rotors there is provided, as a rule, a motor driven barring gear which rotates the shaft at a few revolutions a minute, ensuring that the shaft remains uniformly heated and therefore true, the turbine being kept ready for running up. It was customary to mount this barring gear on the pedestal at the turbine exhaust end. In recent years the barring gear has been mounted at the outboard pedestal where it is much more accessible for operation; at the same time, in that position, it is not exposed to danger of damage by water or steam inadvertently escaping from the turbine gland.

In order to ensure reliability of shafts at high temperatures, an electric furnace is installed. The shaft is slowly but uniformly rotated in the furnace, gradually heated up to a temperature of 850° F. to 1,000° F., kept at that temperature for some hours and then slowly cooled down. During the whole cycle of heating and cooling clock readings are taken at a few points, and from them the deflections of the shaft established. These tests disclose temporary or permanent deflections, stationary in one radial plane or moving angularly. In most instances these phenomena are eliminated by two or three treatments in the furnace and

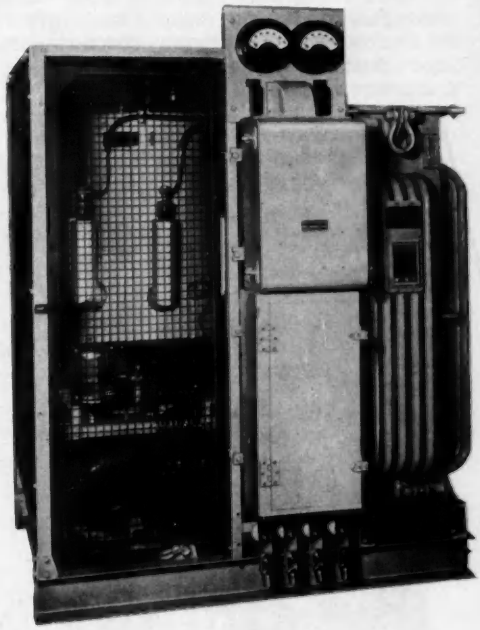


Fig. 37.—Unit type rectifier complete with transformer and control gear.

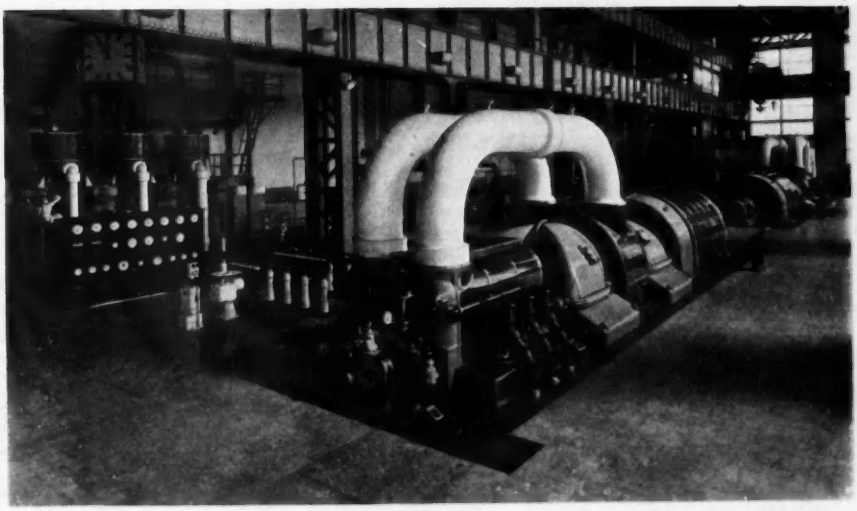


Fig. 36.—Two of the three 37,500 kW G.E.C.-Fraser & Chalmers turbo-generator sets in the Orlando Power Station, Johannesburg.

by final machining; should they not be eliminated the shaft is rejected as, of course, the shaft which in heat shows deflections varying in extent or direction cannot run smoothly under varying conditions of operation.

the number of intercoolers, with ultimate improvement of the compressor efficiency.

Power Station Plant.

Several important contracts for equipment

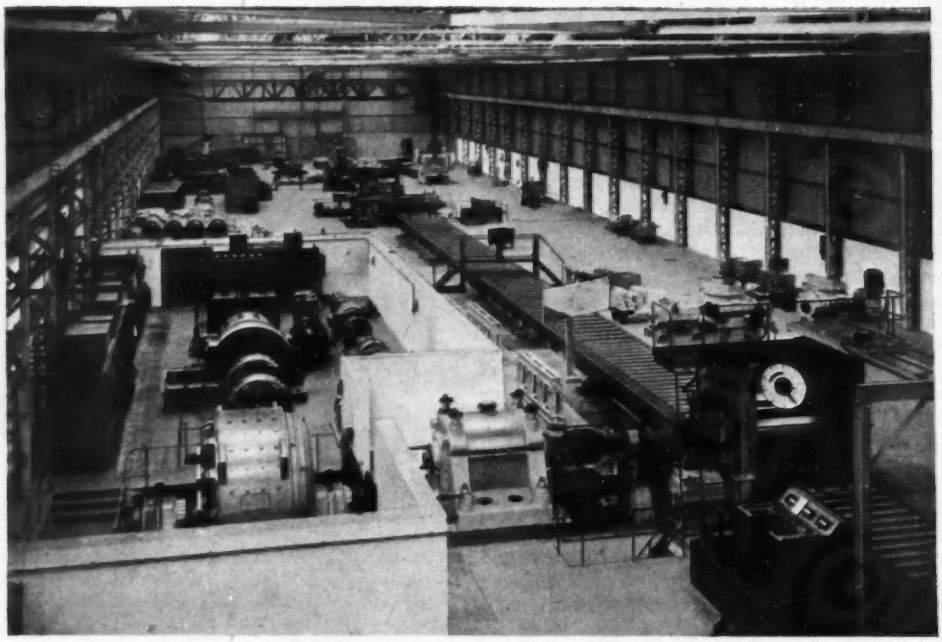


Fig. 38.—A completely electrified 2-high aluminium reversing mill at Birmetals, Ltd., Birmingham. The equipment includes a 1,600 h.p. 0/40/51 r.p.m. D.C. reversing mill motor with Ward-Leonard Ilgner set, and the requisite drives for the run-out tables, coiling and slitting line and flying shear, together with all necessary control gear.

The well-tried materials of superior physical properties now available are used for the impellers of turbo-blowers and turbo-compressors running at higher peripheral speeds. In order fully to utilise the higher velocity, the ratio of the outer diffuser diameter and impeller diameter has been increased. The higher peripheral velocity results in a reduced number of stages, reduction of re-heat, and improved efficiency.

Extensive experiments have been carried out on various designs of compressor intercoolers for the primary purposes of establishing the quantity of heat transferred and the loss of pressure on the passage through the intercooler. The results of these experiments led to the adoption of finned tubes in the intercoolers and to a substantial increase of

for Power Stations are in hand at Witton Engineering Works and Fraser & Chalmers Engineering Works, prominent among which is that for the Meaford Station of the North West Midland Joint Electricity Authority. This contract is for the complete electrical equipment, and includes four 30,000 kW, 11 kV, 3,000 r.p.m. turbo-alternators, together with switch and control gear up to 132 kV, and 26 transformers, four of which are each of 33,000 kVA, stepping up to 132 kV. Sub-distribution switchboards and boiler and auxiliary motors are also being supplied.

Two 37,500 kW, 3,000 r.p.m. units have now been installed at the Orlando Power Station at Johannesburg (fig. 36), and a third set of similar output is being installed. The completion of this installation was delayed

by the loss at sea due to enemy action of the rotor of the second unit, and other important parts of the equipment.

Further turbo-generating units are in hand for C.E.B. Stations at Hull, Woolwich and Newport, while many units are being constructed for export, including two units respectively of 30,000 kW and 12,000 kW for Palestine.

Mercury Arc Rectifiers.

Steel tank pumpless mercury arc rectifiers are now being produced as complete units in sizes up to 200 kW. The rectifiers are complete with switchgear and transformer on a common framework (fig. 37), and are ready for service immediately they are installed on site.

An interesting marine application is a 600 kW grid controlled rectifier equipment installed in one of the Admiralty floating docks. The rectifiers are arranged to operate either from a shore supply or from the Diesel-driven alternators installed in the dock, and are suitable for giving power supplies at the appropriate D.C. voltages for ships in dock. The rectifier cylinders are required to operate in an inclined position and in the confined space available in the dock walls.

Fig. 39.—Individual drive of ring spinning frames in a mill of the Lancashire Cotton Corporation.

Welding.

The demand for the maximum possible output of all classes of munitions of war directed the attention of Government Supply Departments and manufacturing concerns to the potentialities of fabrication by arc-welding. The contribution which this technique eventually made to the national war effort is now being realised as details of the production of the Bailey Bridge, Mulberry Harbour, Pluto, and other projects are released for publication.

Fig. 40.—The new isolating electrode holder.

The Directorate of Industrial Electrical Equipment (D.I.E.E.) of the Machine Tool Control (M.O.S.) early appreciated the necessity for concentrating on the production of the more economical static welding plant, and were instrumental in the publication of British Standard No. 1071, which standardised a range of multi-operator welding transformers, suitable for heavy constructional work.

Development work on A.C. welding plant had been in progress at Witton works for many years before the war, and the Company was therefore well equipped for the production of large quantities of the class of plant to satisfy the urgent demand. A complete range of transformer type arc-welding plant was designed to suit the war-time

requirements of industry, based on the extensive practical experience gained in the fabrication department of the Company's numerous Works, and on information obtained by close contact with shipyards and other industrial undertakings. Equipment was produced from the smallest single operator set designed to meet the requirements of the sheet metal industry, to the largest multi-operator plant capable of welding the heaviest section.

In addition to welding transformers and current regulating reactances supplied during this period, a complete range of weatherproof condensers was designed for correcting the power factor of welding plant where necessary, and a number of special welding cables was also developed and supplied in large quantities.

The increased use of A.C. arc-welding plant during the war period called attention to the fact that although the voltage to earth of the welding circuit was limited to 100 V, there was some danger from shock, especially when welding operations were undertaken in confined spaces or other situations involving special hazard. As the result of representations made by the Factory Department of the Ministry of Labour to the Directorate of Industrial Electrical Equipment (D.I.E.E.) of the Ministry of Supply, a number of manufacturers of welding equipment were asked to develop a suitable safety device which would enable the electrode holder to be isolated from the supply when operating remote from the source of supply.

Initial experiments were made with small-capacity switches (incorporated in the electrode holders), operating main current contactors by means of pilot wires in the welding cables.

This method was elaborate and expensive, and the G.E.C. therefore proceeded to investigate the possibility of providing a 300 ampere switch within the body of the electrode handle. It was realised that although this switch would normally operate as an isolator at zero current (since the arc is normally broken by removing the electrode from the work), the switch must be capable of withstanding numerous operations under full current conditions without excessive pitting at the contacts and without overheating.

Difficult as the proposition appeared at first, the Company eventually succeeded in producing the new electrode holder shown in fig. 40, which is designed to take electrodes up to 4 S.W.G. at currents up to 300 amperes.

Until the lever is depressed the exposed metal parts are completely isolated from the welding supply, and the holder may therefore be handled with safety. The inward movement of the lever operates the spring-loaded, self-aligning contacts which conduct the welding current to the central plunger. The latter grips the electrode by a powerful spring action.

Fig. 41.—Two views of a split unit for use on mobile ground Radar equipments.

It was realised that the main safety feature would be lost if it were possible for the holders to be used with the lever tied in the "on" position. The lever is therefore designed to operate the electrode grip in the "off" position only. This important provision ensures that electrodes cannot be inserted or withdrawn from the grip until the holder has been made "dead" by the release of the switch lever.

In practice the switch contacts have been found to have a long life, but the construction of the holder is such that replacement is simplified. The weight of the holder is 24 ozs.

Fractional Horse Power Machines.

Among the extremely large number of fractional horse-power machines manufactured for the Services during the war, amounting in numbers to well over 750,000, chief technical interest attaches to the split unit for Radar, the aircraft trim tab unit, the magslip, and the camera control motor.

The split unit (fig. 41), which is an essential part of the Radar A.A. No. 6, Mark I equipment, consists of a small alternator driven by

a 3-phase, 3,000 r.p.m. synchronous motor, both mounted on a common shaft which also carries a small 4-bladed paddle, the complete unit being enclosed in a brass housing. The split unit has two functions: first to supply a voltage which would deflect the cathode ray oscillograph in a horizontal direction; second, to make cyclic variations of capacity in the aerial circuit. These functions have to be synchronised with the 400 cycle supply to the modulator and have to bear a definite phase relationship to it.

The deflector voltage generated by the alternator has a frequency of 200 cycles, and its wave form is substantially flat topped for a minimum of 95 electrical degrees during each half cycle. Deviation from flatness has to be less than 2 per cent of the peak value during any period of 5 electrical degrees.

Fig. 42.—Aircraft trim tab motor.

The tolerance allowed on the nominal phasing with respect to the 400 cycle modulator wave is $\pm$ 24 degrees on the 400 cycle time scale. This figure includes allowances due to climatic conditions and to variations in the phase angle of the main petrol-electric set under changeable loads, since the 50 cycle power plant forms the connecting link between the split unit and the Radar apparatus.

The cyclic variations in capacity of the aerial circuit are obtained by rotating a 4-bladed paddle close to two small stubs. A high degree of mechanical accuracy is required since the average air gap between paddle and stub is .007 ins. and all four blades have to lie within $\pm$.002 ins. of the prescribed average position. When the paddle is not rotating it has to be withdrawn until the distance from the stub is not less than $\frac{1}{8}$ in.

At a zero time, defined on the 400 cycle time scale, the physical position of the centre line of the paddle blade relative to the centre of a stub has to lie within $\pm 3\frac{1}{2}$ mechanical degrees from a datum line. This tolerance has to cover all the possible causes of variation already mentioned in connection with the deflector voltage phasing.

The complete unit is enclosed by a brass dome, but the internal spaces can communicate with the outside atmosphere by way of a cylinder filled with silica gel crystals which absorb any moisture in the air which is breathed into and from the unit due to variations in temperature.

Several special methods of testing had to be devised. These were based on the use of a cathode ray oscillograph. The 200 cycle alternator voltage was made to deflect the C.R.O. beam vertically while at the same time the 50 cycle power supply deflected it horizontally. The resulting "Lissajous figure" showed both the wave form and the phase relationship. The figure was viewed through a special cut-out template, and the machine was satisfactory if the whole of the figure was visible.

The setting and phasing of the paddle was checked along the same general lines. The unit was mounted on a special jig that imitated working conditions. High frequency voltage was applied between the paddle and a fixed insulated stub, and the resulting capacity current was used to deflect the C.R.O. image vertically while the main 50 cycle supply voltage deflected it horizontally. These tests proved to be very sensitive and formed a check which could not have been made in any other way. Apart from being quantitative

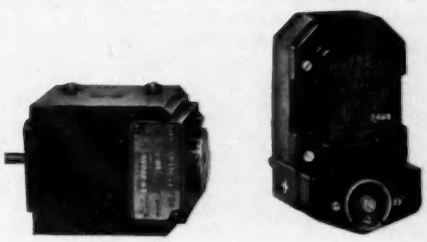


Fig. 43.—Aircraft camera control motor.

they showed up any defects in bearings, or the presence of excessive end-play. A small percentage of the machines were tested under extreme temperature conditions of – 40 degs. C. and + 70 degs. C.

At one stage in the design it was important that the starting and stopping times of the split unit should lie within the limits of $\frac{1}{2}$ sec. and 5 secs. respectively. This was checked by

using a rotating drum contact, first to make and then to break circuit for the required duration, while the "Lissajous figure" for the paddle was observed on the C.R.O.

A small motor of special design known as an aircraft trim tab motor (fig. 42), was developed in 1943 in conjunction with Miles Aircraft Co., to drive the screw-jack device which gives a precise push-pull operation for aircraft control. Although this operation is occasional, it is an exacting one, the motor having to provide a torque of 10 oz.-inches at 10,000 r.p.m. for 1-minute periods, from the 12 or 24 volt D.C. supply of the aircraft. Further, the motor must stop quickly immediately it has completed its work to avoid damage due to overrun, and as a push-pull operation is required the motor must be reversible.

The motor has the usual steel yoke fitted with two salient poles, and a $1\frac{1}{4}$ in. diameter armature of 1 in. core length, the overall dimensions being $2\frac{1}{4}$ ins. diameter and $4\frac{3}{4}$ ins. long.

To obtain a quick stop, an electro-magnetic brake is incorporated having six equally-spaced brake shoes which are pressed on to an aluminium drum by springs giving the necessary pressure to produce the requisite braking. The springs are held off magnetically when the motor is switched on, the supply to the motor passing through the brake release excitation coil. As soon as the motor is switched off the pressure on the shoes is sufficient to bring the armature to a standstill from 10,000 r.p.m. in 15 revolutions. The total weight of the unit is $2\frac{1}{2}$ lbs.

Another small instrument which the Company produced in large quantities, both at Witton and later at a shadow factory in Leicester, is the magslip used for fire control, and for operation in connection with predictors. These instruments had previously been made by instrument makers in relatively small quantities, and before production on a quantity basis could be started the drawings had to be carefully toleranced and new manufacturing methods devised. It is of interest that the methods of production evolved were sufficiently successful for the Admiralty to request that the Company should undertake the management of an additional war-time factory acquired for the quantity production of magslips.

A very small motor was developed in 1939 to drive the mechanism of a special camera used in reconnaissance aircraft to take photographs of the ground below at regular intervals, the photographs being joined together after printing to give a picture map of the ground covered. The motor (fig. 43), of which a very large number were produced, weighs only 10 ozs., and is a totally enclosed D.C. shunt connected machine providing a 1 oz.-inch torque at 3,500 r.p.m. It is operated from the 12 or 24 volt D.C. supply of the aircraft. In the early days of production all motors were fitted with ball bearings, but due to the acute shortage of ball bearings which occurred at a later stage, plain bearings of the oil retaining type were fitted, and it was found possible by giving careful attention to the shaft surface and the hardness of the metal to reduce the friction loss at low temperatures. The motor had to operate within the wide temperature range of – 40 degs. C. to 60 degs. C.

Fig. 44.—Land mine detector.

Land Mine Detectors.

Early in 1944 an urgent order was received for the manufacture of a new type of land mine detector, or "sweep." The first order was for 30 sets to provide equipment for training purposes. The urgency of the order was such that it was allocated the highest priority so that the 30 sets could be completed within three weeks. In view of the fact that

land mine detectors were an entirely new product so far as Witton was concerned, and involved quite a new production technique, it was with considerable satisfaction that the 30 sets were completed a week ahead of time. This first order was immediately followed by others totalling many hundreds, and altogether 25,000 sweeps of various types were produced in a section of the works at Witton specially erected in a very short time for this class of work, and at a shadow factory at Kidderminster. The importance of the work was emphasised by Field Marshal Lord Montgomery (then General Sir Bernard Montgomery, K.C.B., D.S.O.), who made a special visit to Witton on 9th March, 1944, to inspect the sweeps.

The first class of sweeps to be manufactured at Witton were the inductive bridge type used for the detection of metallic anti-tank and anti-personnel mines usually buried at a depth not exceeding 2 ft. The principal elements consisted of a search coil unit, amplifier, control box and head set. In the search coil unit are two ring-shaped coils placed close together with their edges overlapping by an amount which gives a balanced condition when oscillating current is fed into one of the coils. The amount of overlap of the coils is critical, and is adjusted during manufacture to give the balanced condition, *i.e.*, coupling effect is zero and one coil will not produce an induced signal in the other. If now the coils are brought near a metallic object such as a mine, the effect is to increase the coupling and upset the balance, producing a signal which is transferred to the amplifier and thence to the head set, where it is reproduced in the form of an audible note.

The search coil units were built up into a sweep 6 ft. wide (fig. 44), which for operational work on beaches and airfields were much superior to the more usual narrow sweep which the operator had to move from side to side as he walked forward. Later models, for use in the Far East, were tropicalised and completely sealed, and could be used under water. The later types also used a circuit which resembled that of the inductive bridge type, but which was modified by connecting one coil to the input of the amplifier and the other to the output of the amplifier. In the balanced or zero coupled position no signal is heard in the head set. If the search coil unit is placed near a mine the zero coupling will be upset, resulting in the two coils setting up an oscillation which is amplified and heard in the head set. This type is known as a regeneration detector, and has the advantage that the feedback can be controlled to discriminate between clinker and different types of mines.

Power Interlock Drive for Radar.

Early in 1940, at the request of the R.A.F., Farnborough, a synchronised reversing drive for large rotating aerial systems was designed and manufactured for use in connection with R.A.F. Radar aircraft search equipment. Normally, these aerials, of which there were two per set, a transmitter and a receiver, rotated continuously in one direction, but they could be stopped at any position, or reversed, or made to rotate forwards and backwards in the direction of any suspected aircraft. The drive was effected by two 3.65 h.p. slipring induction motors, and the necessary synchronism maintained by coupling the rotor circuits through a resistance, an artificial load being imposed so that the motors ran well below synchronous speed. After tests had been satisfactorily completed on the prototype, the contactor gear was re-designed to fit into a special cubicle which was mounted in the standard R.A.F. heavy vehicle. Production started in November, 1940, and at the same time, at the request of the M.A.P., a contract was placed with another manufacturing concern who were required to produce equipment similar in every detail. Various improvements were incorporated at later stages, notably the introduction of braking by injecting direct current into the stator circuits

Fig. 45.—Airfield lighting control desk.

to give quicker and more accurate stopping.

Altogether 320 equipments of this type were produced at Witton and 180 by the other source of supply.

Control of Airfield Lighting.

During the period of the war when the enemy's air force was concentrating on the bombing of our airfields by sudden sharp attacks at night, frequently at a time when the airfields were being used by our own aircraft returning from a bombing mission, it became essential to devise some method of remote control of all lights on the airfield, so that in any emergency they could be extinguished instantaneously and, after the emergency had passed, restored with the minimum of delay.

A complete scheme was evolved, and several important airfields equipped with apparatus, remote controlled from a central point, to operate all airfield lights including flarepath, boundary, wind tee, inner and outer markers, and in addition to give warnings of crash landings or enemy raiders.

One of the remote control desks used for this purpose is shown in fig. 45. The desk is divided into two halves, the right hand section housing all the push buttons, switches, and control relays, and the left hand section having a miniature plan of the airfield with small indicating lamps representing the position of the various lights and the cardinal points of the compass. In construction, the miniature plan of the airfield consists of an anodized aluminium plate upon which is chemically engraved the plan of the aerodrome showing the position of the runways, buildings and obstructions. Small holes and slots are cut at these points in the plate, and miniature lamps placed underneath which light up when the appropriate push button is pressed. The cardinal points of the compass are also illuminated, and a continuous indication of the direction of the prevailing wind is given from rotating drum contacts and brushes in the base of the wind tee, so that the operator may determine which runway should be illuminated for returning aircraft. The holes and slots in the plate are covered by glasses coloured according to the code adopted by the Air Ministry.

The push buttons in the control desk operate current relays housed in kiosks on the airfield, and the indicating lamps on the desk, being connected in series with the lights on the airfield, thus give a true indication of the lights switched on at any time. The control desk at each aerodrome is situated in the Watch Office. It is of interest that an illustration of one of these desks appeared in the official R.A.F. publication "Bomber Command."

Radar Range-finding Equipment.

Following upon the research work on Radar carried out by the Research Laboratories at Wembley (noted elsewhere in this article), an accurate range-finder was produced in quantity, known as Radar A.A. No. 6, Mk. I, for use in conjunction with Predictor A.A. No. 7, Mk. I, and a twin six-pounder gun. The Radar equipment is mounted concentrically with the predictor, and rotated with it, a power follow-up mechanism being employed. The whole equipment is mounted on a trailer suitable for cross-country travel (see fig. 5).

Fig. 46.—Mounting for 20 mm. Oerlikon gun.

Witton's contribution was the design and production of the mechanical structure to house the Radar, and the input and output drives connected with the power follow-up mechanism. An essential part of the equipment is the "Split unit" described on page 30, in which a synchronous motor-driven paddle causes cyclic variations in the capacity of the aerial circuit. In front of the split unit the

aerial assembly is mounted in the centres of two parabolic radiators, the axes of which have to be very accurately located with respect to the axes of the telescopes of the predictor. The need for this high degree of accuracy brought in its train the demand for a correspondingly high degree of accuracy in machinery and workmanship.

The rotation of the equipment is initiated from the predictor, and in order to provide easy manipulation for the crew to "follow up" accurately a special follow-up mechanism links the predictor with the Radar and consists of a torque amplifier of the capstan drum type. The maximum permissible error between predictor and Radar is $\pm\frac{1}{4}$ deg. Thus the design and production of the input and output drives were of instrument precision standard. The whole of the rotating portion of the equipment is carried on a taper roller track which required special methods of machining to ensure the fine limits required. The complete equipment is fitted to the trailer on a three-point suspension mounting.

Some of the problems arising due to operational requirements are of interest. The complete equipment had to be capable of going into action within four minutes from the time of arrival on site. Due to the rubber shortage—none was allowed for this contract—special frameworks supported on leaf and coil springs were produced to carry the Radar units, the spring suspension being so designed as to ensure that in no case were the units subjected to an acceleration exceeding 5 g. vertically and 3 g. laterally and longitudinally. The equipments had to operate satisfactorily between the extremely wide temperature limits of – 30 degs. C. to 71 degs. C.

Sherwen Electromagnetic Vibrating Table.

Applications of the Sherwen electromagnetically operated vibrating table to the war effort have been extensive and varied. Amongst the many projects in which they were used may be mentioned, Mulberry Harbour—Phœnix and Whale (concrete caissons and floating roadway sections, respectively)—F.I.D.O. (Fog Dispersion), tank landing mats, deep tunnel shelters and railway sleepers. More recently they have been in big demand in connection with the Government scheme for the manufacture of prefabricated reinforced concrete houses.

A particularly interesting application of the Sherwen table has been its use for the sorting of diamonds, an operation previously carried out laboriously by hand. The former method involved sieving the diamonds into a series of sized fractions and then examining the stones of each grade one by one under a glass and classifying them according to body, *i.e.*, according to their height when resting in a stable position. As may be imagined, this is a lengthy and not very efficient process. The Sherwen sorting table performs the same operation with much greater speed and with virtually 100 per cent. efficiency. The vibrating mechanism used for sorting has also been applied to sieving the stones, again with much greater speed and efficiency than is possible by hand. In view of the widespread use of industrial diamonds, such an automatic process offers considerable advantage over hand sorting.

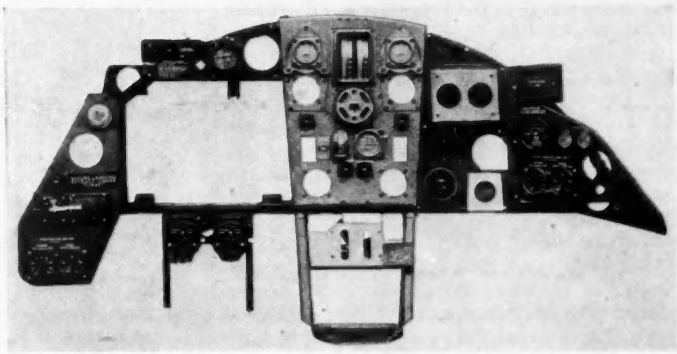


Fig. 47.—Pilot's dashboard panel for Wellington aircraft.

Armament.

Gun Mountings.

Preliminary conversations began in June, 1944, to decide whether the production of gun mountings for the well-known 20 mm. Oerlikon gun could be undertaken. The first contract was placed in July, and the first mounting was ready for inspection by October 3rd (fig. 46).

The principal features of the mounting include : (*a*) a fabricated conical steel pedestal formed from $\frac{1}{2}$ in. thick steel plate ; (*b*) an outer housing cast in Admiralty gunmetal, mounted on top of the pedestal ; (*c*) an inner

housing fitted into the outer housing so as to permit free rotation; and (*d*) a trunnion bracket securely bolted to the inner housing so that they rotate together. This provides the means of support for the cradle bracket which carries the gun itself.

This mounting incorporates the following details: (*a*) means of stowing the gun in a

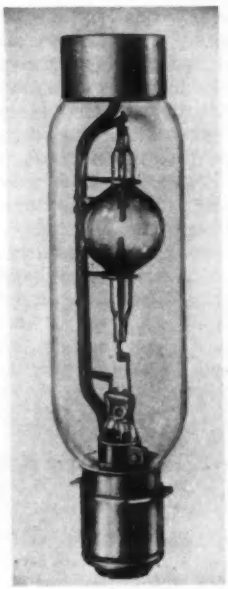


Fig. 48.—500 watt compact source lamp.

definite position relative to the base, achieved by a spring-loaded pin; (*b*) a spring balance device to counteract the weight of the gun so that the gunner can operate with a minimum of effort; (*c*) an armour-plate shield fitted to the trunnion and rotating with the gun, giving protection to the gunner from the line of fire; (*d*) a cartridge bag to collect empty cartridge cases.

A special plant was laid down for the production of the spring axis and shoulder pieces, and many thousands of these parts have been supplied.

Ammunition for the Army.

The Express Lift Company's Northampton factory was devoted to the production of high explosive shells, smoke shells, practice shot and proof shot, 4.5 in., 5.25 in., and 6 in., and a complete new factory was built and plant laid down for the production of 7.2 in. shells. This involved building a new transformer substation, and the installation of additional air compressor plant. An emergency gas producer plant was installed, comprising one 20 therm and two 5 therm units.

For Woolwich Arsenal, punches and dies for use in the manufacture of rifle bullets were produced in considerable quantities.

As sub-contractors to Messrs. David Brown & Sons (Hudd.) Ltd., several thousand of lay-shafts for the Merritt/David Brown 4-speed gear box for infantry tanks were processed.

The shafts were of 60 tons nickel steel, and

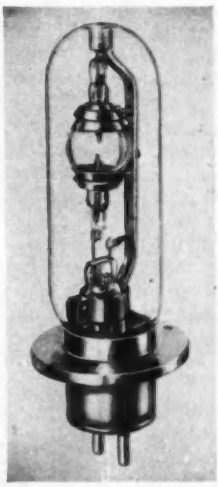


Fig. 49.—250 watt compact source lamp.

the processes involved are grinding to correct diameter and length, cutting splines, drilling and counter-sinking.

The splines are generated by a hobbing process to limits of .001 in. in 10½ in. parallelism.

Aircraft Equipment.

The first contract for the Royal Air Force was entered into early in 1939, and production steadily increased until at the peak it provided equipment for 90 aircraft per week.

Some of this work was carried out in the parent factory of the Express Lift Company at Northampton and, in addition, "shadow" factories were opened in Northampton and at Sileby in Leicestershire, which were devoted entirely to aircraft production.

The work carried out included wired electrical instrument panels used by pilot, bomb-aimer and crew of the Wellington (fig. 47). Practically the entire output of panel equip-

ment for this famous aircraft was produced in G.E.C. factories. Similar equipment was made later for the Warwick.

Other equipment produced for the Wellington included wind-brake flaps, de-icing tanks, tail-plane leading edges, and anti-submarine devices, as well as distribution and junction terminal boxes, and vitreous enamelled resistances.

LAMPS AND ILLUMINATION.

The war years have seen a remarkable growth in the appreciation of good lighting. The enforced hardships of blackout and long

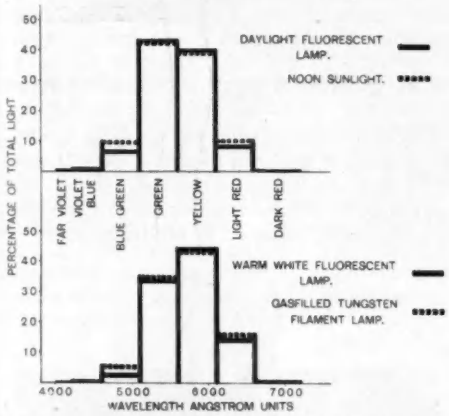


Fig. 50.—Spectral luminosity distribution diagrams for daylight and warm white fluorescent lamps.

hours of work under artificial light have made us realise the importance of proper lighting to good health, quite apart from its value in increasing speed of production and quality of product. A clear lead in this matter was given to the community in "The Factories (Standards of Lighting) Regulations," of January, 1941, which prescribed a minimum of 6 foot candles "over those interior parts of the factory where persons are regularly employed"; and even this standard is "without prejudice to the provision of additional illumination" where the particular work requires it. This increase to 6 foot-candles from a pre-war value of 1 foot-candle effected an enormous improvement in conditions in many factories, particularly as it came at much the same time as the introduction of mains-voltage fluorescent lighting.

The 5 foot fluorescent lamp with its good colour and comparative freedom (as compared with tungsten filament lamps) from radiant heat, was probably the most important single contribution by the lamp industry to the war effort. Fluorescent lighting made working conditions pleasant in underground factories and other places blacked out day and night, and work on the improvement of lamp quality and on its applications was vigorous.

The mains-voltage lamp was not, of course, the only new lamp developed during the war years; and industrial lighting has not been the only field of progress. Knowledge of the eye under dark adaptation conditions has been increased, and much has been learned of how to make the most of a little light; this knowledge has been used, for example, in the lighting of aircraft cockpits. Study of the visibility of distant objects has been intensive, so that there might be a better understanding of such problems as camouflage, and the best use of searchlights and flares. For this purpose photometric measurements were made up to 30,000 feet, the greatest height, it is believed, at which photometry has been attempted.

It is interesting, too, to note some of the ways in which lamps used for one purpose before the war have been applied for another purpose during the war; for example, sodium discharge lamps have been used by the R.A.F. for training during daylight in the art of night flying and landing. In this scheme the pilots wear special eye-glasses which filter out all light with the exception of the characteristic monochromatic sodium radiation at 5890—5896 Angstrom units, and night flying conditions can be closely simulated in the brightest sunlight. The R.A.F. have also used many thousands of Osira red neon floodlighting lamps in mobile flashing beacons. Compact source lamps, figs. 48 and 49, are used in R.A.F. "Bombing Teachers" which project a moving panoramic aerial view of the ground in such a way that bomb aimers can receive initial instruction in bombing ground targets.

Fluorescent Lamps and Operating Equipment.

A new class of powders of halo-phosphate composition has been evolved at the Research Laboratories for use with the low pressure mercury vapour discharge. The important characteristic of these materials is that they enable a range of "white" colours of good colour rendering properties to be achieved without the use of mixtures of powders, which is the present practice. The photometric performance of the new powders compares well with the best of the existing materials.

Continued development of the 80 watt daylight fluorescent lamp has resulted during the year in an improved life and efficiency rating.

This lamp was the only one available during the war, but new applications of fluorescent lighting need lamps of different characteristics. The first new design is a 4 foot lamp 1½ inches in diameter rated at 40 watts, and other designs will follow; but it must be remembered that although the basic principles are the same for all these lamps, each presents its own problems in design and production. For this reason it is impossible to make available immediately all the many types which the lighting engineer could use. The new post-war ratings will be fitted with a bi-pin cap which is neat and convenient for fixing. Two colours of lamps are now available, namely, "Daylight" and "Warm White"; the latter is particularly suitable for recreational forms of lighting. Fig. 50 shows the luminosity distribution at different wavelengths of the "Daylight" fluorescent lamp compared with noon sunlight, and the "Warm White" lamp compared with a gasfilled tungsten lamp.

Special circuits have been devised which enable fluorescent lamps to be started without the delay associated with the usual starting switches. Other circuits being examined enable the lamps to be operated from higher frequency supplies (greater than 250 c.p.s.) for special purpose lighting, for example, on trains and aircraft. An experimental installation operating on direct current has been made in conjunction with the London Passenger Transport Board in one of their Underground coaches; 24 inch, 20 watt lamps of the warm white colour have now been in operation for some months. Among detailed improvements in circuit arrangements are the design and introduction of a range of tapless chokes and capacitors of elongated shape which can easily be embodied in a narrow channel on the fitting. Difficulties associated with non-interchangeability of glow and thermal starters have been overcome by the use of the same four-contact base on both types of starter.

With the ending of the war, work on cold-cathode lighting has been restarted. Improvements in fluorescent powders and in the processing of the tubes themselves have resulted in a greatly improved performance. This specialized form of lighting is particularly valuable for "tailor-made" installations, and attention is being paid to this aspect in the design of tubes and associated equipment.

High Pressure Electric Discharge Lamps.

Various projection applications have been considered with the objects of obtaining efficient optical utilization of compact source lamps and of satisfying the operational circuit requirements. The large scale use of compact source lamps for projection has been studied during the past year. So far as the optical aspects are concerned, the most outstanding result has been in the field of projection for 16 mm. black and white film, where it has been shown that the compact source lamp gives a screen illumination several times greater than that obtainable with tungsten filament lamps.

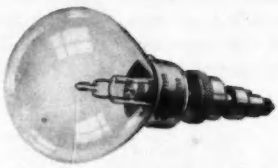


Fig. 51.—A signalling type lamp with special filament and cap.

For some projection applications in film studio work it has been necessary to find a way of burning the lamps at any angle. This has been done by a new application of the "magnetic deflector" method of arc control.

Fig. 52.—Lamp designed especially for use in tanks.

Further progress in the design of circuits for the compact source lamps has been made. In particular a fully automatic circuit has been developed which allows the lamps to "simmer" at a low wattage when not in use, to restart automatically even when hot if the supply is interrupted and then restored, and to operate a blower which cools the lamp and fitting only when the lamp is in full operation. This "simmering" principle has led to some interesting problems which have been successfully met by the design of a special choke. The problem of the "intermittently operated" or "flashing" compact source lamp has been actively studied. There are many applications in which effective efficiency can be increased by two or more times by arranging that the lamp is operated at a high wattage only during the very short intervals when required, as for example in film projection where the lamp is flashed only when the shutter is open. An

experimental projector has been built using this principle.

A considerable step forward in the quality of high pressure mercury vapour lamps for street and industrial lighting has been recorded during the past year. The rated lives of the 80, 125, 250 and 400 watt Osira high pressure mercury vapour lamps have been increased substantially.

Discharge Lamps and Devices for Special Purposes.

Many problems involving the use of very high intensity flashes of short duration from special discharge lamps have arisen during the war. The flashes are obtained by discharging capacitors charged to a few thousand volts through a suitable gas; generally speaking one of the rare gases, preferably krypton or xenon, is used. Lamps dissipating up to 4,000 watt-seconds per flash at a frequency of 1 every 2 or 3 seconds for special photographic purposes have been produced, as well as some small lamps dissipating only 1 or 2 watt-seconds per flash. Flashing lamps for operation in special circuits up to frequencies of the order of 5,000 per second have been made for high-speed cinematography. Intermediate types have also been used for various stroboscope applications.

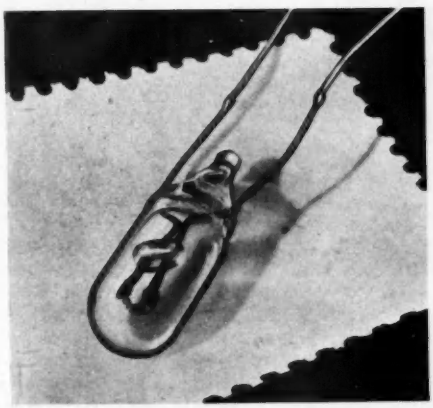


Fig. 53.—Miniature size medical lamp resting on a postage stamp.

With the termination of the war, floodlighting lamps have come under review. The possibilities of fluorescence are being explored and, on the circuit side, improvements may make it possible to eliminate the Tesla coil for starting purposes.

Mercury discharge lamps have been designed for direct operation from 24 volts D.C. supplies to provide convenient low power sources of ultra-violet radiation for exciting fluorescent instrument dials in aircraft. The lamp is about the size of an ordinary automobile side-lamp, has a simple, robust construction, and requires little auxiliary equipment. Experimental lamps for operation from a 12-volt battery have also been made.

The range of "Osira" laboratory lamps has been extended by the inclusion of a lamp with a zinc vapour filling.

A new recording tube (type NGC), is intended for use where space is limited, *e.g.*, for time-marking on the drum camera in a cathode-ray oscillograph. Writing speeds up to 200 cm./sec. can be obtained at frequencies up to several kilocycles per second.

A new arrestor (type CCE), designed as part of an equipment to protect London Passenger Transport Board sub-stations, discharges at approximately 2 kV and passes repeated surges of 2.5 coulombs.

Filament Lamps.

The importance of visual intercommunication systems during the war has necessitated the manufacture of special signalling lamps both for night and daylight use. One such lamp, used in the Aldis daylight signalling lamp, is illustrated in fig. 51. It is rated at 12 volt 36 watt.

Heavy vibration associated with armoured fighting vehicles, particularly tanks, set many problems. Fig. 52 illustrates a tank lighting lamp, using filament wire of special composition, with two short filaments in series mounted on heavy copper wire supports.

Among the miniature lamps made for the Services is one designed for use in instructional equipment. It is rated at 2 volt 0.4 watts; its overall length is only $\frac{7}{16}$ in., and its diameter $\frac{3}{16}$ in. A further lamp, in this instance for medical use, is seen in fig. 53. Its size can be gauged from the postage stamp on which it rests.

High Current Density Arc Lamps.

Late in 1940, at the height of the heavy bombing attacks on England, work was started in conjunction with Air-Commodore Helmore, C.B.E., on the design of high current density arcs of high power. Whereas the standard ground searchlight consumes from 10 to 15 kW in the arc, the new lamp was to consume 140 kW, and was to be housed in the nose of a fast aircraft. Its purpose was to illuminate an enemy aeroplane immediately before and during attack by fighter aircraft. A 37 mm.

positive carbon was used passing a current of the order of 1,200 amps. Because of the intermittent operation required, it was found possible to supply the power from lead-acid accumulators with suitable circuit arrangements. A para-elliptic mirror gave the desired

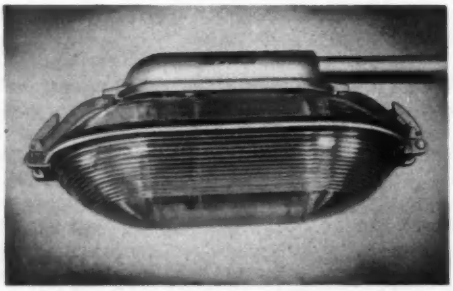


Fig. 54.—"Dioptrion" or double dish lantern.

spread of light which was emitted through a relatively small hole in the nose of the aircraft. The complete equipment, called the Helmore-G.E.C. Turbinlite, was installed in several different types of aircraft.

From this work was developed a searchlight for use on the ground, of considerably greater beam divergence than that normally used for anti-aircraft operations. The positive carbon size was increased to 64 mm., and an entirely new type of negative carbon was used in the form of a rotating disc. With a current of 4,000 amps, the energy consumed in the arc was 600 kW, making it the biggest artificial light source so far known. The arc was first used with a 5 ft. diameter mirror, and the high power necessitated a water-cooled housing. Later, when it was desired to test beams of smaller divergence, a 10 foot diameter mirror was tried giving intensities of some thousands of megacandles.

Photometry.

It was realised before the war that with the rapid evolution of electric discharge lamps, lamp quality could no longer be appraised by reference to efficiency and life alone. By 1940 early experimental forms of apparatus had been described for determining by photoelectric means the lumens and colour rendering properties of discharge lamps. This work has now been revived, and an experimental apparatus of advanced design has been in regular use during the past year. Routine measurements have been made of lumens, colour and colour rendering properties, particularly of tubular fluorescent discharge lamps; also the integral transmission of colour filters.

In this apparatus, light is dispersed from the diffusing window of a 5 foot photometric integrator, in which the lamp is operated. In the spectrum image plane a mask of appropriate shape is arranged so as to control the proportions of light throughout the spectrum. This dispersed light is subsequently transmitted to a photocell operating in conjunction with a universal photoelectric photometer so as to give any required overall spectral sensitivity. One mask provides a spectral response corresponding to that of the C.I.E. Average Eye, and others enable the trichromatic coefficients of the colour of the light to be measured directly on the C.I.E. Trichromatic system. Another group of masks provides the means of measuring luminosity in eight agreed spectral bands. All these characteristics can be determined while the lamp is in the photometric integrator.

In order to measure more precisely than has been possible by earlier photographic methods the time-intensity and lumen seconds of photoflash bulbs, an experimental photometer has been devised. This consists of a spherical photometric integrator with a diffusing window

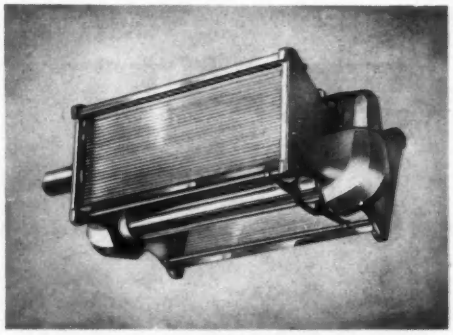


Fig. 55.—Refractor plate lantern for sodium lamps.

in its side from which a photoelectric emission type cell receives light. This photocell is connected to a cathode ray oscillograph equipped with a single stroke time base. The oscillograph is triggered simultaneously with the closing of the circuit of the primer of the photoflash bulb. A camera attached to the oscillograph records a photograph of the time intensity trace superposed on an illuminated squared graticule in front of the cathode ray tube, and by counting the squares under the time intensity curve the lumen seconds can be derived.

LIGHTING APPLICATIONS.

Prior to 1945, fittings for use with fluorescent lamps were confined to those suitable for industrial purposes, but since the beginning of the year it has been possible to design

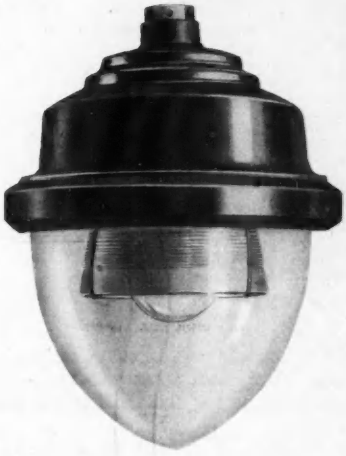


Fig. 56.—New Wembley lantern for side street lighting.

fittings suitable for the commercial and other fields. Prominent amongst these is a reflector made of diffusing plastic material which has qualities of high efficiency, good appearance and good light distribution, including the emission of an adequate amount of light in the upper hemisphere. This ensures a pleasing appearance of the surroundings due to light reaching the ceiling and upper part of the walls. Fittings have also been designed to apply localised lighting to shop counters and display areas. These fittings embody specular reflectors to ensure a good downward concentration of light, louvres of glass or plastic to mask the direct view of the lamp at low mounting heights, and top apertures to give adequate ceiling illumination. Two types have been made, one for illumination of horizontal display areas, such as counters and floors, and one for vertical as well as horizontal illumination for use where counters are backed by display shelves.

Multiple lamp fittings for general shop lighting in a variety of styles have also been produced. Research has been devoted to the problems of shop window lighting with fluorescent lamps, as the result of which two types of multiple lamp shop window reflectors have been designed, one embodying a simple white enamel reflector, the other employing mirror glass reflectors. The latter is definitely the more efficient reflector, but in addition to being more costly involves the provision of facilities in the top of the window which may not always be practicable in existing premises. Simple arrangements for housing the gear can be embodied with either reflector.

An interesting investigation was made of the best method of illuminating motor-car bodies for spraying, particularly for inspecting the paint-work. The highly polished and curved surfaces and the small differences in colour involved, introduce awkward problems. They were solved by the use of five sets of fluorescent lamps in trough reflectors so located that the observer can "cover" all parts of the car body with reflected images of the troughs.

An outstanding application of fluorescent lamps is their use underground. Work is being actively prosecuted on this subject in collaboration with the Mines Department, since it is possible that these lamps may effect a revolution in underground lighting conditions.

The desire to use aluminium for the bodies and reflectors of lighting fittings has led to a long programme of work on corrosion. Many different kinds of alloy and surface treatment are being tested by exposure at stations in different parts of the country; in consequence the factors controlling the incidence of corrosion and the methods by which it can be avoided are becoming better understood. Street-lighting lanterns exposed in some places during the war without proper maintenance have also given valuable data on the effects of corrosion.

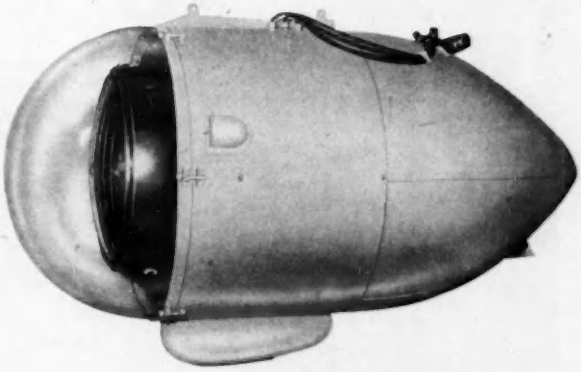


Fig. 57.—Leigh light.

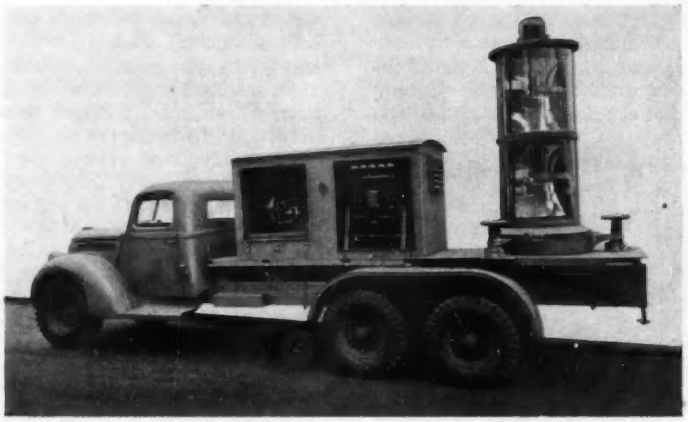


Fig. 58.—Mobile aerodrome beacon for Russia for use at very low temperatures.

Information thus obtained is being applied to new lantern designs, one of which, the "Dioptrion" or double dish lantern is shown in fig. 54. This unusual design employs horizontally burning high pressure mercury vapour lamps, for lighting traffic routes. It is made almost entirely of glass, the two refracting dishes controlling a large portion of the light emitted by the lamp ; supporting metalwork is reduced to a minimum. A new cut-off lantern for street-lighting uses totally enclosing glassware which gives improved stability of performance and reduces the effects of soiling.

Figs. 55 and 56 show two others of the new designs. Fig. 55 shows a refractor plate lantern for use with 85 watt or 140 watt sodium lamps for traffic route lighting. Fig. 56 shows a side street unit which will accommodate a variety of optical systems for the smaller Osram and Osira lamps.

A long series of model experiments was made on the lighting of roundabouts, with special reference to a particular roundabout in a Midland town ; based on the results, some unusual lighting is being installed. Another interesting investigation has been into the visibility of road traffic signs. This was undertaken on behalf of the Illuminating Engineering Society for the Ministry of War Transport. Laboratory techniques built up when studying war-time problems were found of value in this work.

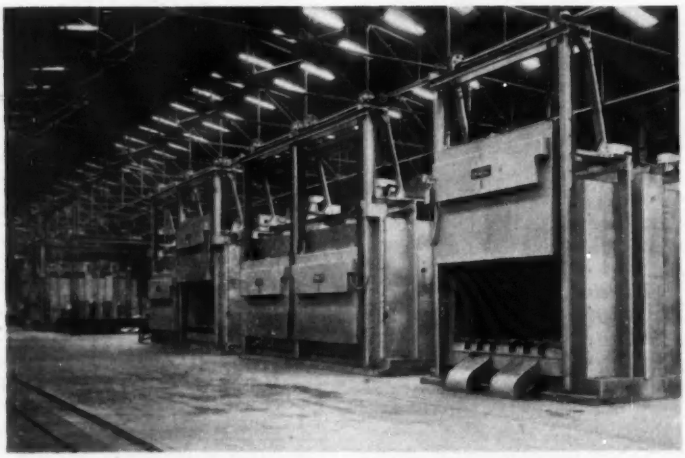


Fig. 59.—Typical installation of batch type furnaces comprising 3 twin chamber 720 kW furnaces and one 300 kW mechanical hearth furnace.

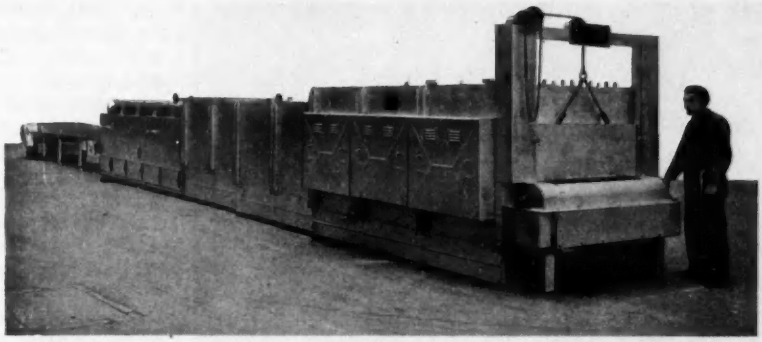


Fig. 60.—Glass annealing lehr for operation at temperatures up to 600 degs. C., loading 36 kW.

A contribution to anti-submarine warfare was the production of many Leigh Lights of Nacelle type (fig. 57) with controllers and switchboards for use on Catalina and Liberator aircraft. Mobile aerodrome floodlights have been considerably improved during recent years, both in optical performance and in reliability in service. Fig. 58 shows a typical unit as supplied to Russia, which was designed to operate at low temperatures. War-time developments in aircraft and alterations in procedures have, however, effected radical changes in the requirements for the lighting of aerodromes, and great interest is now centred round this subject. Much work has been done to find the best design of contact lights for use in fog, and on the design of approach lights.

Visibility and Camouflage Investigation.

The study of the atmosphere previously reported, enabled many visibility problems to be attacked which were previously insoluble. The action of anti-aircraft searchlights was investigated by calculation and experiment, and these methods of treating the problem initiated work which has since been carried further by other establishments. In one series of experiments an aircraft model, illuminated by a model "searchlight" beam, was photometered in the mirror distribution photometer generally used for lighting fittings, and its "candlepower" in various directions was found. The use of searchlights against military ground targets was also studied by model experiments. An interesting study was made of aircraft reconnaissance flares. A suggested improvement of the flares was investigated in detail, both by calculation and experiment. It was necessary to obtain candlepower distributions of the flares, and an experiment was made in collaboration with the Armaments Design Department of the M.A.P. in which these distributions were found outdoors in daylight. This was no easy task, since the flare has a leaping flame two or three feet long, and produces volumes of smoke; it has to be burned in a considerable current of air to simulate its fall on a parachute. The laboratory experiments on flare performance were made using small electric lamps in an artificial

Fig. 61.—Lamp plant for stoving paint on wings and other aircraft components.

Fig. 62.—Infra-red heating plant for stoving paint on jettison petrol tanks for aircraft.

atmosphere of water, rendered hazy by the addition of an emulsion. The appearance of targets on the ground was studied with flares of different types at various heights and spacings. As a result of this work a new type of flare was evolved by the Armaments Design Department which was successfully used in the Battle of the Ruhr.

For the guidance of those planning night operations a chart was prepared showing the possible light at night from the moon and the stars throughout the year. The preparation of this chart was subsequently made an official responsibility, and in the latter part of the war was issued for a number of latitudes to cover all theatres of operations.

At the beginning of the war, the Laboratories assisted in the initial work on air-raid decoys. The decoys finally used, based largely upon this early work, saved targets from many enemy bombs.

Help has been given to the official camouflage establishments in the design of their viewing rooms and in experiments. Among many other problems dealt with was that of the optimum painting for Coastal Command aircraft engaged on anti-submarine patrols, and (in collaboration with other establishments) the conditions in which ships can be picked up from the air by the light of flares.

ELECTRIC HEATING.

The rôle of electric heating in war is not greatly different from that which it is called on to fulfil in times of peace, and opportunities for spectacular developments are less plentiful than in some of the newer branches of engineering. This does not mean that progress is lacking in such important directions as the design of space heating equipment, where economy in the use of materials and ease of installation have led to very marked expansion in the use of electric unit heaters, or in the development of cooking equipment to meet the peculiar and severe demands of the Royal and Merchant Navies. It means rather that in time of war development continues, in the main, to follow the paths which have been well defined in time of peace, but with a tempo increased in sympathy with the urgency of the demand.

The war did, however, produce some novel heating problems, many of which were associated with the need for naval vessels to operate for long periods in Arctic waters. Mechanisms which operated satisfactorily under less rigorous conditions needed special protection against the severe weather experienced in these regions. One of the more important problems was that of preventing the liquid

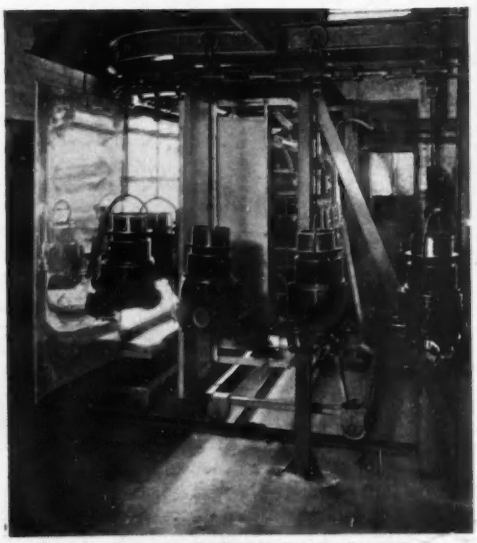


Fig. 63.—Lamp plant, in use for stoving paint on aero engine components, loading 36 kW.

used for cooling the barrels of quick-firing anti-aircraft guns from freezing when the guns were out of action. The heaters for this purpose had to be very robust, for they had not only to withstand the climatic conditions, but had also to remain unaffected by the severe shock and vibration to which they were necessarily subjected during firing. Elements of the sheathed-wire type (well known before the war in radiant boiling plates and immersion heaters) proved entirely suitable, and heaters

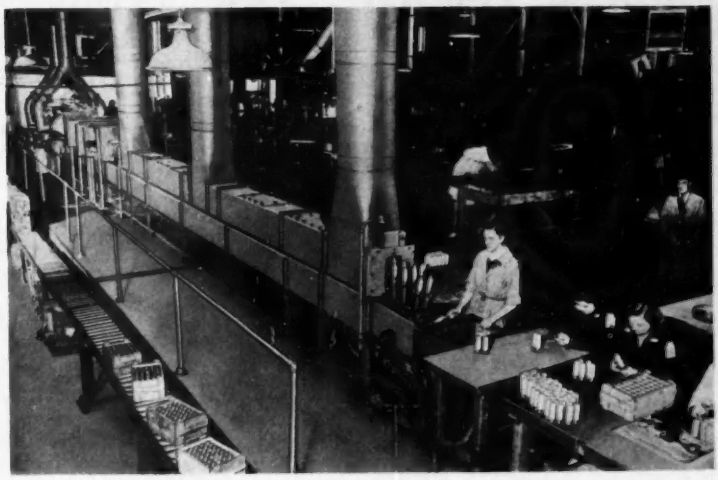


Fig. 64.—Production line for spraying and stoving paint on artillery shells, showing spray booths, high intensity radiant heating plant, and forced convection cooling tunnel.

embodying these elements were supplied in very large quantities to naval vessels of all types. Sheathed wire elements were also used for heating storage tanks for the cooling liquid, for heating gun breech mechanisms, and (in portable form), for protecting delicate mechanical apparatus from frost damage and for preventing condensation in electrical machinery.

Process Heating.

It is, perhaps, in the field of process heating that electric heating has made its greatest war-time contribution, and it is certainly here that the increase in the tempo of development has been most marked.

Radiant heating, or infra-red heating as it is frequently called, which was virtually unknown in this country before the war, has rendered vital service in many directions by enabling bottle-necks in production to be removed. More recently the use of high frequency heating has been greatly extended. Before considering these newer methods, however, it is of interest to note the progress which has taken place in the development and application of electric furnaces.

Electric Furnaces.

One of the more striking developments is the great increase in the use of vertical cylindrical batch furnaces; to-day, most of the cold rolled steel strip produced in this country is bright annealed in furnaces of this type. Some of the individual installations are very large, one employing 29 furnaces and about 300 pots. The popularity of these furnaces is very largely due to the uniform heating to which the charge is subjected from all sides, and to the simple nature of the pot closure which is so constructed that there is absolute control of the special atmospheres which are employed. Furnaces of the same general design are used for surface hardening crankshafts, cylinder linings, etc., by the nitriding process.

There has been a large demand also for horizontal hearth batch type furnaces for the general heat treatment of both ferrous and non-ferrous metals and alloys. An installation of four of these furnaces is illustrated in fig. 59.

Gas carburising and gas malleablising have received close attention, and a vertical batch type furnace with its associated gas producing

equipment and insulated chamber for the slow cooling of charges has been installed for large scale experimental work.

A lehr for the annealing of glass bulbs, vacuum flasks and tumblers at temperatures up to 600 degs. C. is among installations which have been supplied for purposes other than metal treatment (fig. 60). The lehr, which is 65 ft. long, is divided into three zones, each having separate automatic temperature control. The articles to be annealed are conveyed on a 3 ft. 9 in. wide stainless steel mesh belt, and by suitable adjustment of the temperature in successive zones, may be subjected to any desired heating schedule. A feature of the lehr is the special sheathed wire heating element which is used. Each unit of this element has a loading of 1.5 kW, and the units may be withdrawn separately and replaced without the plant being closed down.

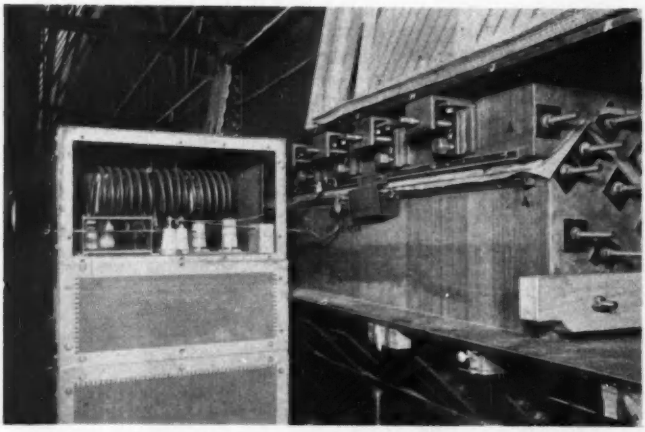


Fig. 65.—High frequency heating set in use for the production of laminated spars for Hornet aircraft.

Radiant Heating.

The final control of rate of heating in an electric furnace is usually thermostatic. In the case of radiant heating such a system—although not impossible—has not yet been at all thoroughly developed, and production plants must be designed to give precisely the rate of heat transfer which the process in question demands. This necessitates individual experimental investigation of all enquiries in order that the permissible tolerances may be properly determined. A valuable addition recently made to the experimental equipment provided at the Research Laboratories for this purpose is a 144 kW fully adjustable lamp plant complete with conveyor.

Paint drying continues to be the most important application, and several interesting installations which have been supplied during the year serve to illustrate the direction of recent progress. The plant in fig. 61 is used for stoving a series of coats of paint and putty on wings and other components of high-speed aircraft. These materials are used for building up a smooth finish over rivets and joints, and it is claimed that the treatment enables the speed of an aircraft to be increased substantially. The materials were originally allowed to air dry, and the time taken on a wing for application and drying was just over 71 hours. Radiant heating reduced this to 19 hours, of which less than 2 hours are taken up by the stoving operations themselves. This plant affords a good example of the facility with which temperature control problems can be overcome provided the production requirements are thoroughly understood. An upper temperature limit of 80 degs. C. was specified in order to avoid the risk of damage to internal components and wiring which are fitted at the stage when the finishing operations are carried out. Rapid heating to this temperature was desirable in order to keep the stoving time reasonably short, and the result was achieved by operating the lamps at their full voltage during the initial part of the stoving cycle and then maintaining the temperature constant at a safe figure by operating them through an auto-transformer at a reduced voltage. The whole of the control gear is fully automatic. The operator has merely to set the selector switches to the positions indicated for the component being handled and for the coating (paint or putty) to be stoved. The appropriate lamps are then switched in circuit, the voltage is reduced at the correct time and the plant is switched off when stoving is complete.

The plant in fig. 62 illustrates the enclosed construction adopted for modern lamp plants, while that in fig. 63 illustrates the versatility of this process. In the plant shown paint is being dried on heavy engine castings.

Progress is being made continuously in the use of radiant heating in other fields such as the setting of synthetic resin adhesives, the softening of plastic materials, the gelling of

polyvinyl chloride paste coatings on fabric for leather-cloth manufacture, etc. A plant has been installed at the Research Laboratories for the continuous heat treatment of coated fabrics on a small production scale.

Lamps are not the only source of radiation, and it has been established that in certain instances alternative sources offer definite advantages. For example, when paint is to be stoved on massive articles of regular shape such as artillery shells, it is both permissible and desirable to use a much higher intensity than lamp equipment is capable of providing. Fig. 64 shows a plant used for this purpose. The shells, which are supported on a slat type conveyor, pass through a spray booth and then into the stoving oven which is built on furnace lines, with nickel-chromium resistance elements mounted on ceramic formers on the side walls. On leaving the oven, they pass through a forced convection cooling tunnel and emerge sufficiently cool for handling. The stoving time for the thermo-setting synthetic resin paint specially developed for this purpose varies from 30 seconds to 3 minutes according to the weight of the shell.

Fig. 66.—A 20 kW high frequency heating set.

High Frequency Heating.

The use of eddy currents at frequencies in the kilocycle range for heating metals has long been well understood and has been applied industrially to a limited extent, principally in melting furnaces. Frequencies in the megacycle range have also been used in a few special cases, the heating of the electrode systems during the manufacture of radio valves being one of the most important. Dielectric heating, however, is virtually new as an industrial process.

Both branches of high frequency heating have now been explored sufficiently to enable one to form a picture of their possibilities and of their proper place vis-a-vis the older methods of heating. That they have a very useful function to fulfil is now firmly established, though, as the equipment required is necessarily rather costly, their chief application will undoubtedly be to processes in which full benefit can be taken of their special characteristics. Thus eddy current heating surpasses all other methods when extremely rapid surface heating or very carefully localised heating is required. It ensures close uniformity of heat treatment on a mass production scale without calling for highly skilled labour, and on account of its speed, can easily be fitted into the production line. Dielectric heating comes into its own when thick slabs of material of poor thermal conductivity must be heated uniformly and rapidly, and when thin sheets of such materials must be heated at extremely rapid rates.

At the present stage of development, it is difficult to be certain of the order of importance of all the applications. The surface hardening of steels will undoubtedly take a high place; all manner of steel components can be treated and, in certain cases, by using very high rates of power input, self-quenching, by conduction from the heated skin to the cold inner core, may be used to replace the customary water quench. Other important eddy current applications are for brazing, soldering, tempering and annealing.

The preheating of thermo-setting plastic moulding materials is likely to become one of the more important dielectric heating applications, and the Research Laboratories have co-operated in a special investigation of this subject on behalf of the Ministry of Supply. Many of the problems arising in the industrial use of dielectric heating for this purpose were subjected to systematic analysis, and data were collected on the relation between the results with this method of heating and those with the alternative convection and radiation

methods. Other important uses are for seaming thermo-plastic sheet materials, for setting glue in wooden assemblies (see fig. 65), for the manufacture of laminated plastic materials, and for certain special moisture evaporation processes.

Fig. 67.—Selectest.

The range of valve oscillator sets at present available for industrial use extends from 100 watts up to 20 kW, with intermediate ratings of 1 and 5 kW, the powers mentioned being in all cases H.F. outputs. The smallest set is suitable for seaming thermo-plastic sheets, for spot gluing wood veneers, and for soldering very small articles. The 1 kW set is used chiefly for pre-heating moulding materials. The 5 kW set can deal with the largest quantity of moulding material normally used at a time in a press, and is suitable for many wood gluing and moisture evaporation processes. It is also used for soldering and brazing, and for the surface hardening of small areas. The 20 kW set, fig. 66, may be used for higher power dielectric heating processes such as plywood manufacture, and for many eddy current heating processes.

The same principles have been followed in equipping the High Frequency Heating Laboratory at Wembley as for the sections dealing with other process heating equipment. Facilities are available for full production scale experiments with equipment including work-handling tables for surface hardening and presses for plywood manufacture and for plastic moulding. The sets available for this work include an experimental unit having an output of 75 kW.

Domestic and Industrial Appliances.

Although, during the last year, production for purposes connected with the war effort was the chief activity of the sections of the Company dealing with heating equipment, some return was made to the development and manufacture of domestic and industrial heating appliances. Work on these had virtually been at a standstill throughout the war years, production being restricted to that necessary to meet essential Government requirements. Technical progress was consequently confined to that required to enable unusual service to be met. Examples are the development of a special lightweight water heater for use in aircraft, refrigerators for use under tropical conditions, and heavy duty cooking equipment for use in warships.

Development work on cookers and boiling plates has now been resumed. A new rod type oven thermostat has been developed as a matter of urgency in view of the large leeway to be made up in the supply of cookers.

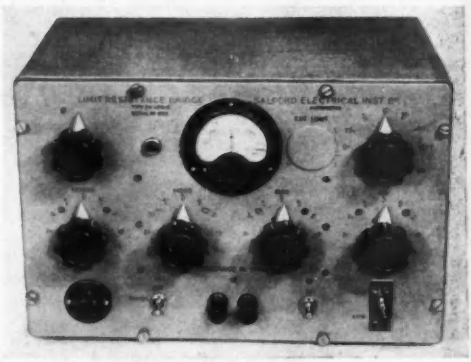


Fig. 68.—Limit Resistance Bridge.

An interesting feature of this instrument is the leaf spring hinge system employed in the switch mechanism in place of the more conventional pivots. This enables lost motion resulting from frictional effects to be avoided, and the operating forces required to be more accurately determined.

In view of the vital importance of maintaining British agriculture at its highest efficiency, priority is being given to the development of heating equipment for agricultural purposes. The increased use of the combine harvester has led to considerable interest being taken in the use of electrically-heated grain driers,

which offer advantages in the directions of ease of temperature control, avoidance of delays occasioned by pre-heating, and simplicity of operation.

MEASURING INSTRUMENTS.

Scientific progress during the war owed much to the development of suitable measuring equipment. It may indeed be said that the rate of progress in any new venture is largely determined by the availability of measuring apparatus. This fact was realised at an early stage in the drive towards centimetre wave Radar and it became standard practice to develop measuring equipment to match each step forward in the development of oscillators. Signal generators were, in fact, frequently built round new types of oscillator before the design of the oscillators themselves was complete. This policy has been fully justified and to-day equipment is available for producing standard signals for all frequencies up to many thousands of megacycles per second.

It is not only in the field of centimetre wave Radar that rapid progress has been made. War-time demands have stimulated many developments in measuring instruments and techniques in every branch of science, including the adaptation of well-known methods to new applications. It is not possible in the space available to mention more than a few of these developments, but some idea of their scope may be gained from the range of applications which they cover. This includes not only electrical and radio instruments, but also photo-electric and photometric devices, and a wide variety of instruments for making mechanical measurements and for investigating the properties of materials.

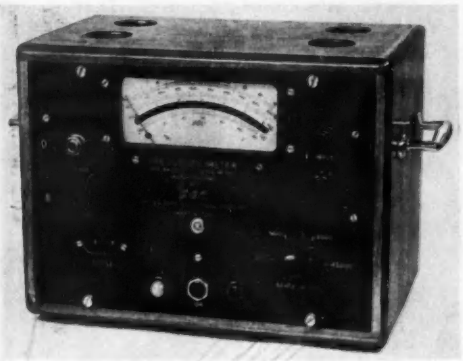


Fig. 69.—Electronic frequency meter.

METERS.

The main advance in general purpose meters has been the introduction of the miniature 1½ in. range designed for panel mounting and incorporating a new and robust movement suitable for the severe conditions prevailing in the Services.

A new multi-range test meter, the "Selectest," fig. 67, can be employed for the measurement of current and voltage with direct and low frequency alternating current. It can also be used for measuring resistance. The first models, made to Service specifications, have 3 mA movements, but meters with greater sensitivity are also being produced.

Fig. 70.—Crystal calibrater.

BRIDGES.

A recently developed series of bridges caters for a wide range of impedance measurements, covering resistances from 0.1 to 10 megohms, inductances from 100 microhenries to 10 henries, and capacitances up to 0.01 microfarads. These bridges operate either on direct current or at a frequency of 10 kc/s.

An interesting modification of a Wheatstone Bridge (fig. 68), has been designed for a bulk sorting of resistors with regard to tolerances from a standard value. The resistor under test is placed in a jig and by operation of a change-over switch, positive and negative tolerances can be checked from limit positions on a meter scale.

A further innovation is a radio frequency bridge for the measurement of partial capacitance and conductance. The experimental model operates at a frequency of 1 Mc/s., but the design is suitable for use up to 50 Mc/s. Both the generator and the detector have one side earthed and the balance condition is unaffected by the earth capacitances of each

side of the capacitance under test. The bridge is most suitable for the direct measurement of interelectrode capacitances in valves, but may also be used to determine capacitance and conductance between any two conductors even though other conductors are present. This type of measurement can be carried out by means of a Schering Bridge, but the present method can be used at much higher frequencies.

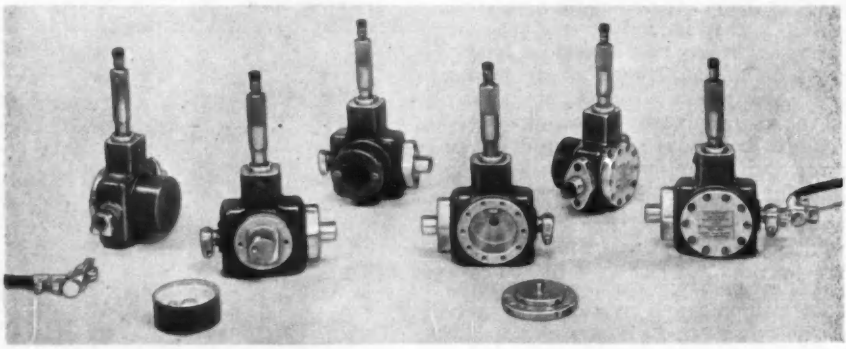


Fig. 71.—Several aspects of a cavity wave meter. It has a preset adjustment enabling it to operate from 2,700 to 5,000 Mc. At any one preset position the frequency coverage is 3 per cent.

Frequency Meters and Wave Meters.

Many different methods of measuring frequency and wavelength have been exploited. Some of these are electronic devices incorporating quartz crystals; others, intended for the highest frequencies, use resonant lines or resonant spaces whose dimensions bear a close relationship to the wavelength.

Low frequencies from 15 c/s. to 45 kc/s. can be measured by means of the electronic instrument illustrated in fig. 69. The unknown signal is applied to a valve to produce a square wave of constant voltage of the same frequency as the signal. The square wave is then applied to a rectifier which produces a current whose magnitude is proportional to the frequency. The probable error is about 3 per cent.

In several models designed for frequencies up to 250 Mc/s. or higher the unknown signal beats with a variable frequency oscillator whose frequency can be checked at predetermined points by means of the harmonics of a quartz crystal.

This method and other similar methods wherein the unknown frequency is referred back to a low frequency standard have been used experimentally at frequencies as high as 30,000 Mc/s. (wavelength of 1 cm.), an accuracy of about 1 part in 105 being obtained. Measurements of this kind require a high degree of skill and experience on the part of the operator, and no simple apparatus exploiting this principle has been prepared. The resonator type wave meters described below are more suitable for general use at these very high frequencies.

Another type of precision frequency meter dependent on quartz crystals is known as the crystal calibrater. This instrument (fig. 70), incorporates a crystal oscillator which may be set by a selector switch to 100 kc/s., 1 Mc/s., or 5 Mc/s. The output from the oscillator is mixed with the unknown signal and when the latter is close to a harmonic of the oscillator a beat note is produced which after suitable amplification can be detected by telephones. To assist in determining the order of the harmonic, an auxiliary oscillator is incorporated which may be set to either 30 or 40 Mc/s. With suitable care this instrument may be used for measuring frequencies of many

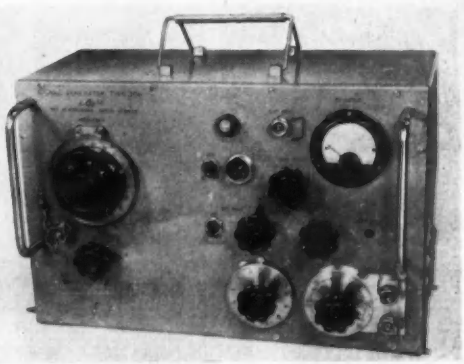


Fig. 72.—Signal generator, No. M.927B.

hundreds of megacycles to an accuracy of 0.01 per cent.

Co-axial line wavemeters have been used for absolute measurements at wavelengths in the 3 to 30 cm. range. These lines are short circuited at one end and have an adjustable shorting plunger for tuning the length to half-wave resonance. A probe is used for coupling to the source and a loose-coupled crystal detector indicates resonance. An accuracy of about 0.2 per cent is obtainable.

Several cavity resonators have been designed for accurate measurement over a narrow range of wavelengths in the centimetre band. In one of these (fig. 71) the tuning is effected by altering the length of the cavity. A small loop is used for feeding the input signal and a crystal detector is again used as a resonance indicator. The accuracy in this case is about 0.01 per cent.

Signal Generators.

A wide range of generators for use at frequencies from a few cycles to thousands of megacycles per second has been developed during the war. Frequencies from 50 c/s. to 100 kc/s. are covered by beat frequency oscillators, while a pulse modulated generator covering the range 5–55 Mc/s. in four bands is shown in fig. 72.

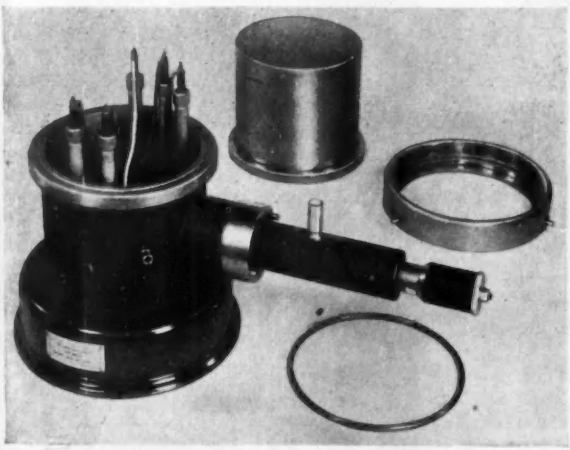


Fig. 73.—Signal generator for use in the centimetre wave band. The top has been removed, showing the filters for the supply leads. This model can operate at any wavelength below 10 cms. by using a suitable Klystron oscillator.

In the centimetre wave band signal generators, taking the somewhat unusual form illustrated in fig. 73, have been built round klystron oscillators. Special features of these models are the piston attenuators, and the copper sulphate filters which are used for the D.C. leads.[1]

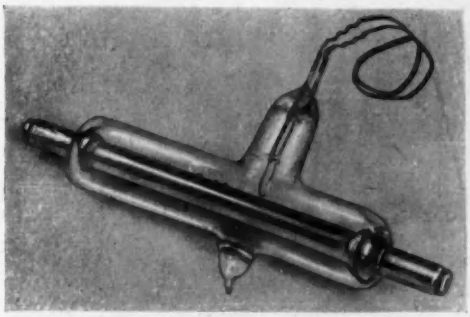


Fig. 74.—The E.1199 diode for voltage measurements in coaxial lines at decimetre wavelengths. The rod anode forms part of the inner conductor of the coaxial lines.

Many other signal generators covering the whole radio spectrum have been developed and fuller details may be given at a later date.

Decimetre and Centimetre Wave Measurements.

Many instruments, in addition to those already described, have been developed for use in the decimetre and centimetre wave bands. Many of these have been incorporated as integral parts of the short wave circuits. Thus, a diode for measuring peak voltages has been constructed with a rod type anode (fig. 74) which forms a part of the inner conductor of a coaxial transmission line.

Low powers have been measured by using a small lamp with a tungsten filament in conjunction with a resonant section of a transmission line or of a wave guide. The actual power is determined by measuring the D.C. resistance of the lamp filament, a quantity which varies rapidly with temperature and so with the high frequency power being dissipated in the filament. These instruments are usually described as bolometers; one of them —a co-axial line bolometer—is shown in fig. 74. Higher powers have been determined by inserting an attenuator, which can usefully be made from a length of coaxial cable, between the source and the bolometer. High power

1. Radio Measurements in the Decimetre and Centimetre Wave Bands: Clayton, Houldin, Lamont and Willshaw; paper read to Radio Section of the I.E.E., Nov. 7th, 1945. (To be published later.)

has also been measured calorimetrically by determining the rise in temperature of a column of water used as the main dissipative element in the high frequency circuit.

Fig. 75.—The Schuil telephotometer for brightness measurements of distant objects during daylight.

Impedance measurements have also been carried out by suitable use of sections of transmission lines.

This very brief account has been included here as an indication of the scope of G.E.C. activities in this important field of measurements. A full acount has recently been given elsewhere.[1]

Photometric Instruments.

Reference is made elsewhere in this article to some of the war-time problems which the illuminating engineer has been called upon to solve. As in other fields, the solution of these problems has called for the development of precision instruments, and quite a wide range of photometric measuring devices has resulted. The following are amongst those which are of more general interest.

A universal photometer, based on precision instruments which have been described previously,[2] is intended for use in all precision measurements, particularly where very small amounts of light are available, and a high degree of stable amplification is consequently required. The apparatus consists essentially of a photocell photometer unit (*i.e.*, a photocell, an electrometer valve, and a grid leak up to 100,000 megohms, all in one evacuated bulb), and a valve stabilised supply.

When used with a Preston type liquid filter this photometer has a response similar to an "Average Eye."

The polar nephelometer was developed for the measurement of the distribution of light scattered by a small element of atmosphere when illuminated by directed light. In this device a powerful beam of light is passed through a small aperture, and is partially scattered by the air beyond. The brightness of the scattered light is measured by a specially designed low-brightness photometer. A black light-trap is provided beyond the beam and the whole assembly consisting of photometer, aperture plate and light trap can be rotated so as to measure the brightness from various known angles.

The apparatus is most sensitive; it is possible to measure from an aircraft at 30,000 ft. the distribution of light scattered from the atmosphere at that altitude.

Fig. 76.—A strain viewer, showing an enlarged image of a wire seal.

1. Radio Measurements in the Decimetre and Centimetre Wave Bands: Clayton, Houldin, Lamont and Willshaw; paper read to Radio Section of the I.E.E., Nov. 7th, 1945. (To be published later.)

2. Development of Commercial Photo-electric Photometers: Winch and Harper, *G.E.C. Journal*, Vol. III, No. 3, August, 1932, p. 149.
Design of Precision Commercial Photo-electric Photometers: Winch and Machin, *G.E.C. Journal*, Vol. VI, No. 4, November, 1935, p. 205.

The Schuil telephotometer, fig. 75, is used to measure the brightness of distant objects from aircraft during daylight. It is a very compact instrument consisting of the optical system of a prismatic monocular telescope with the addition of a prism photometer field at the principal focus. A small frosted lamp provides the comparison brightness. It is possible to measure the brightness of distant objects subtending only a few minutes of arc while the instrument is being held in the hand.

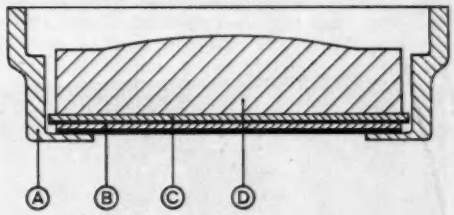
As the measurement of projectors requires longer ranges than could be obtained indoors, and outdoor measurements at night were ruled out during the war by the black-out regulations, a long range daylight photometer was devised to enable such measurements to be made out of doors by day. The essential feature of the arrangement, which is unaffected by strong light, is a telescope with a small aperture at the principal focus which is aligned so as just to cover the image of the projector. In the actual measurement the eye piece is replaced by a photocell.

In meteorological observations and in certain experiments on visibility, one has to observe the range at which a large black object just disappears against the sky. A device has been developed for use with a pair of binoculars, which enables disappearance ranges to be determined with objects which are actually well within these ranges. By a simple optical device, the instrument produces an accurate simulation of the effects of added haze which is based upon the haze actually existing. From the amount of added haze a multiplying factor is determined which, applied to the actual range, gives the disappearance range. This instrument, which has several possible applications, is believed to be the first of its kind in which the simulation of haze is exact and not empirical.

Industrial Measuring Instruments.

That the field of electronics is rapidly extending its coverage to all branches of industry and engineering, is readily indicated by a brief list of some of the measuring instruments which have been developed recently: layer thickness meter, magnetic sorting bridge, radio frequency crack detector, vibration analyser, strain gauge amplifier, enamelled wire pin hole tester, and projection strain viewer. Some of these have already been described in this journal.[3]

The strain viewer used for detecting strains in glass to metal seals in valves, has been of great value in the development of new valves



A—A semi-rigid plastic moulding with rectangular opening in the base.
B—A zinc plate coated on its lower side with an adherent conducting layer of carbon.
C—A piece of absorbent pulpboard, bearing on its lower side a coating of cereal.
D—The pellet or cake of depolarising mix.
The various parts are assembled in the order shown, and the resulting complete cell is stacked, by means of the nesting tray, into batteries.

Fig. 77.—Sectional view of one cell of a layer type battery.

and other electronic devices. It consists essentially of an optical projector which throws an enlarged image of the seal on to a viewing screen.

Mirrors are used to give sufficient path length in an instrument of reasonable size. Fig. 76 shows an image of a wire seal.

The pin hole tester is of particular interest to manufacturers of enamelled wire, and is arranged to detect flaws or pin holes in the enamel in a simple and automatic manner. The wire is passed through a mercury bath and any contact between the wire and the mercury due to pin holes in the enamel is recorded on a telephone counter.

The layer thickness meter can measure the thickness of a non-magnetic coating on a base of magnetic material. The coating forms the air gap in the magnetic circuit of a small transformer contained in the exploring head. The primary of the transformer is supplied with a constant current and a voltmeter measures the voltage induced in the secondary circuit. This voltage varies with the air gap, and so the meter may be calibrated to read the thickness of the coating.

BATTERIES.

The battery industry, which since its inception about seventy years ago, has been producing cells of more or less the same general type using a cylindrical zinc can, both as the container and the electrode, has been so stimulated by the demands of the war that fundamental changes in design have been introduced, resulting in a much greater utilisation of active material and a greater economy in volume. The "layer battery" by which name

[3] Electrical Progress and Development, *G.E.C. Journal*, Vol. XIII, No. 3, February, 1945, p. 109.

the new type is known, has been made in large numbers during the war for service use, and will have many peace-time applications. It was known before the war in a crude form, and was marketed on a limited scale.

Fig. 78.—A comparison of the layer and can type construction for dry batteries.

The layer battery as made by the G.E.C. was developed at the Research Laboratories of the Company, and manufacturing methods were worked out by the Battery Works at Witton. A moulded plastic collar or tray (A, fig. 77), with the major portion of the base removed to form a rectangular opening or window, holds together the various elements of each unit and automatically spaces them. The moulding is formed so that one will "nest" with another of the same type. A zinc plate (B, fig. 77), is placed in the tray, with its lower side coated with a conducting layer of carbon bonded with synthetic resin. The coating is impervious to penetration by the electrolyte. The zinc side of the plate forms the negative of the cell, while the carbon side becomes the positive of the cell underneath, contact between the two being made when the two trays are "nested."

The production of a satisfactory battery of this type depends chiefly upon the qualities of the conducting coat. It is by no means easy to realise simultaneously the necessary qualities. Too high a proportion of binder will naturally mean that particles of carbon may be completely insulated from one another and result in a layer of very high ohmic resistance. On the other hand, an increasing risk of penetration by electrolyte will follow a reduction in the binder. The electrolyte used in these batteries is of a penetrating nature and the layer must be absolutely proof against electrolyte for several years. In addition, the layer must be non-brittle and firmly adherent to the surface of the zinc in order that the necessary individual plates can be safely blanked out from sheet, for naturally the expense of individually coating millions of small parts would be prohibitive.

On the top of the zinc plate a piece of absorbent pure pulpboard "C" is placed, having on its under-surface a coating of starchy matter mixed with other ingredients. This starch coating is of course applied in bulk to continuous rolls of pulpboard. With the chemicals which are introduced into the cell by means of the pellet and with a carefully graded measure of water this starch forms a sticky absorbent film on the zinc surface. Naturally, as is common in all batteries, a mercury salt is also introduced to amalgamate the zinc surface, this being necessary to reduce parasitic actions. Finally, a cake of depolarising mix, "D," known as the "pellet," is placed on top. The pellet contains all the elements necessary for the complete activation of the cell. On its upper face it has a

Fig. 79.—Automatic dry cell voltage testing machine.

projection or hump, which protrudes through the tray on top of it and makes contact with the carbon side of the zinc plate of the upper cell. The various parts are assembled in this order, and the resulting complete unit is bound up under pressure and coated with wax. The finished stack is a strong, well-sealed unit, easy to assemble into a complete H.T. battery. Obvious advantages are the absence of soldered joints between the cells and the elimination of waste space. There is also a considerable economy in zinc, which no longer has to act as a container. The layer type of battery gives approximately 70 per cent more output per unit volume, and very small batteries for special purposes can be constructed on the layer principle. Finally, the "shelf test" of layer batteries is excellent. A comparison of the construction of the two types of battery is exhibited in fig. 78.

Where a very small battery is concerned, the layer construction is far simpler than the can type. Batteries can be made by this method which are impracticable by ordinary methods, and this opens up possibilities of their use in very small portable receivers and in deaf-aid equipment using valve amplifiers.

The can type of battery has also been greatly improved, particularly as regards uniformity and reliability, improvements which are a direct result of the stringent specifications of the Services in connection mainly with portable radio transmitter-receivers. An important factor in the increased uniformity was the development of an automatic machine for sorting out individual faulty cells before assembly to ensure that those which are assembled into a battery comply with the high standards required. The machine (fig. 79), which works to a higher degree of accuracy than any previous machine of its type, can be operated by unskilled labour. The cells to be tested are fed into the chute on the left. The cells are automatically taken up one at a time between a pair of contact fingers which connect the cell into a bridge network, where its potential is compared with a fixed value. Any difference in potential is amplified and passed on to the grid of a gas-filled relay which controls a deflector. The deflector operates to accept good cells and these are delivered on to the upper right hand chute. If the cell potential is below the correct figure, the deflector does not operate and the cell is then diverted on to the lower chute. The sensitivity is such that two cells a second can be tested to an accuracy of 5 millivolts. Over fifty million cells have been dealt with by two machines since they were installed.

A great deal has been done to improve the uniformity of voltage of single cells and this has been so successful that the overall voltages of the assembled batteries have become so uniform that difficulty has been experienced in measuring them sufficiently accurately on a testing line. Faced with the problem of rapid measurements of voltage with an accuracy of better than 0·05 per cent, electronic devices have had to be developed which enable this to be done with comparatively unskilled labour.

The arduous conditions under which batteries had to function during the war, in jungle and desert, and at extremes of temperature and humidity, made it necessary to conduct research with the object of devising means of retarding the deterioration which starts in all cells as soon as they are made, the reduction of parasitic actions, and the improvement of moisture-proof insulation between individual cells. The results have been most successful, and this, together with the

Fig. 80.—An infantryman equipped with a Walkie-Talkie (portable transmitter/receiver radio set) for use in the field. Utmost economy of space is essential and batteries of layer type construction are used exclusively.

experience gained in the tropicalisation, not only in construction but in packing, will be applied in appropriate forms to all types of primary batteries for use overseas.

Batteries have been used during the war in large quantities, not only in the obvious fields of torch and radio equipment, but in many applications for all three services where a compact, light source of power is required. In many cases they have been used to fire fuses in weapons. Their chief use has, however, been in communications to supply power for portable transmitter receivers, an example of which is shown in fig. 80.

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